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A METHODOLOGY FOR ANALYZING CLASS III SUPPORT AT THE BATTALION LEVEL

THESIS

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Preface

The importance of the resupply of fuel to mechanized ground combat forces cannot be overstated, for without fuel, the combat force rapidly becomes ineffective. The purpose of this research effort was to develop a methodology for use in evaluating the tank battalion's ability to resupply itself with sufficient fuel to preclude a break in continuous operations.

The methodology utilizes a hybrid model to simulate the consumption of fuel in an attrition induced environment. It is sufficiently detailed to provide the user with an audit trail for the purpose of analysis; yet, robust enough to support analysis on alternative systems of refuel operations. It is sufficiently flexible to support the modeling of other mechanized force structures to include the task force.

I would like to thank my thesis advisor, MAJ Dan Reyen, for his guidance in developing the methodology, explaining a multitude of topics, and endless hours spent reading drafts.

Finally, I am grateful to my wife, [redacted] for her love, tolerance, and support throughout this thesis effort. I also wish to thank my daughters, [redacted] [redacted] and [redacted] for understanding when playtime was interrupted by homework.

John K. Langhauser

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Abstract

The tank battalion's success in combat depends, to a great extent, on the ability of the logistical system to provide adequate support. The primary objective of this research effort was to develop a methodology for use in evaluating the ability of the tank battalion to resupply itself with fuel.

The methodology includes a model that is predictive and sufficiently realistic for use as a decision support tool. It combines analytical and Monte Carlo techniques. This model is analytic in its use of classical Lanchester theory to deterministically model the attrition of tanks and resupply vehicles. Recognizing the parallels between the attrition of equipment and the consumption of fuel, Lanchester's equations, as expanded to represent combat between heterogenous forces, were also used to model fuel consumption. Stochastic techniques were incorporated in the model to represent the randomness of the combat environment. The actual number of surviving vehicles able to conduct refuel operations was determined by a draw from a binomial distribution.

The result of this effort is a robust model that the U.S. Army Armor Center can use as an analytical tool to assist in the analysis of Class III combat service support systems.

CHAPTER I

Background and Problem Identification

Success in combat is the result of being able to rapidly project combat power from one point to another point on the battlefield and the ability to maintain that same combat power through a system of continuous and effective provisioning. Thus, combat power is a precarious balance of mobility and sustainability; to overweigh the importance of either factor is to destroy the delicate balance and result in an unintended loss of combat power (28:48-49).

Historical Perspective

After the success of the campaign in Brittany, Patton's Third Army took advantage of the German's sporadic opposition. The Third Army fought to the Seine River and secured bridgeheads by 25 August 1944 (18:55-56). Patton's corps had reached the Seine almost two weeks ahead of the 7 September target date (32:217). The morning of 26 August, Patton's forces attacked from their bridgeheads and began the exploitation of the German forces. Again, resistance was scattered and Patton's forces raced towards the Meuse River. Third Army crossed the Meuse on 30 August and the exploitation ground to a hault for lack of fuel (18:56).

Throughout military history, one of the great weaknesses of logistics has been the lack of transportation to

support of the exploitation and pursuit phases of warfare. This weakness cannot always be blamed for failures to follow up the success of victory, but in the case of Patton's Third Army, the spirit was there and the gasoline was not (22:672).

The Concept Based Requirements System

The concept based requirements system provides a systematic approach for ongoing analysis; the end result of which is to identify future needs of the Army as well as to resolve deficiencies associated with current battlefield capabilities. Thus, the concept based requirements system serves as the focus for all conceptual, developmental and evaluative efforts in the Army. It insures that the Army is trained, equipped, and organized to execute its current doctrine. As part of the concept based requirements system, each mission area proponent of the Training and Doctrine Command (TRADOC) develops a mission area concept that describes the capabilities required of that mission area to execute the current umbrella concept. This Mission Area Concept, in conjunction with the present assessment of Mission Area Threat, provides the basis for Mission Area Analysis. Mission Area Analysis refers to the proponent's assessment of the battlefield tasks required to be accomplished in support of the Mission Area Concept and the proponent's ability to execute these same tasks. The mission area proponent employs operations research and

system analysis techniques, among others, to examine its ability to accomplish its war time missions and evaluate the potential applicability of emerging technologies. It is from analysis such as this that deficiencies in doctrine, training, organization, and materiel, at the operational and tactical level of war, are identified. Corrective actions are then developed and prioritized (8:Chapter 2,7-9).

The deficiencies identified as a result of the Mission Area Analysis process and included in the Battlefield Development Plan are corrected through one of four methods. First, doctrine is examined; a determination is made as to whether or not doctrine needs to be changed in order to solve the dilemma. If so, new or revised publications are distributed, if not, then the training program is evaluated to ascertain whether changes will correct the deficiencies. The next resort is to determine if possible changes to force design will alleviate the deficiency. The final step is to determine whether a materiel solution is required to resolve the problem. Regardless of the nature of the corrective actions required to overcome the deficiencies, the concept based requirements system's objective is to provide combat capable forces (8:Chapter 2,9-11).

The Problem

The U.S. Army Armor Center, at Fort Knox, is designated as the proponent for the Close Combat (Heavy) Force. As such, the Armor Center conducts Mission Area Analysis with

respect to efforts directly related to the generation and application of combat power by mechanized and armored forces for the purpose of defeating the enemy (9:Chapter 2,3). In conducting its Mission Area Analysis, the Armor Center performs a continuous review of its mission area and updates the Mission Area Development Plan to incorporate changes to correct mission area deficiencies. These changes can result from changes in the threat, missions assigned to the Close Combat (Heavy) Force, new studies, field unit feedback, a revised mission area concept, technology breakthroughs or even major revisions in allocation of resources. Currently, the Mission Area Analysis process is applied using AirLand Battle doctrine as the umbrella concept and Close Combat (Heavy) as the Mission Area Concept (8:Chapter 2,7-9).

Results of Mission Area Analysis indicate that combat service support elements must be modernized with the same intense effort as the combat forces that they support. The trend is to enhance the lethality of armored fighting vehicles through the development of larger weapons that are capable of higher rates of fire and at the same time to augment the survivability of the vehicles through increased armor protection, speed, and agility. All of this seems to imply greater demands on the combat service support element's ability to resupply fuel (17: 2-4).

To date, the logistic support structure has successfully supported the J-series tank battalion and tank

heavy task force (generally a tank battalion with one or more of its organic tank companies replaced by a mechanized infantry company) in an European training environment. However, concern has recently been expressed regarding the ability of that same support structure to provide adequate fuel to enable all elements of the battalion task force to conduct continuous operations (10:60). Mission Area Analysis efforts, to include analysis of several sample data collections, have caused a revision of the fuel consumption rates of the Abrams tank. The increase in fuel consumption rates translates to a corresponding increase in the Force Development Consumption Factor (gallons per km). The M-1 Abrams Force Development Consumption Factor was revised from 2.67 gallons per km to 4.04 gallons per km. Certainly this increase of over fifty percent is significant. Concern continues to grow as the Army fields a product improved Abrams tank (M-1A1, a heavier version of the M-1 with a larger caliber main gun, additional armor protection, and an enhanced NBC protective system) with an even higher fuel consumption rates and a Force Development Consumption Factor on the order of 4.3 gallons per mile. Despite the additional tonnage resulting from enhancements and raised fuel consumption rates, the basis of issue plan reflects no change in fuel truck authorizations.

The importance of logistics to the success of the battle has increased as the scale and complexity of war has

progressed. Therefore, it is not an exaggeration to state that the threat to combat service support forces on future battlefields will far exceed that experienced in the past. Nevertheless, it is in the forward edge of the battle area that the extremely vulnerable combat service support vehicles must continuously operate while resupplying the fighting force. Analysis must be conducted to evaluate alternative concepts of resupply. Near and far term solutions are more than likely to result in changes to doctrine, training, organization, and equipment (17:4).

The need of the M-1, M-1A1 and M-2 units to resupply themselves repetitively in the context of AirLand Battle is of genuine concern to the Close Combat (Heavy) community. Currently, the Directorate of Combat Developments at the Armor Center has no analytical tools available to conduct analysis of the combat service support system. It is the sensitivity of the Class III resupply system to attrition, the operational constraints inherent to combat between modernized forces and a myriad of other factors that demands a simple but effective analytical tool to assist in the analysis of Class III combat service support systems (26:1-4).

CHAPTER II

Doctrine and Potential Methodologies

Doctrinal Description

The battalion S-4 has primary staff responsibility for the battalion task force's supply, transportation, and field service functions. Class III, also referred to as POL (petroleum, oil, and lubricants), is one of the many different classes of supply that the S-4 must intensively manage for the battalion while it is in combat. The battalion S-4 is assisted by the support platoon leader. It is the support platoon leader's responsibility to coordinate the requisition of all POL products and receipt for them upon arrival. The support platoon leader's responsibilities also include the preparation of the POL products for delivery as well as the actual delivery of them to the battalions' using elements (16:Chapter 8,6).

The battalion S-4 officer continuously maintains a Class III forecast. As input for the development of the forecast, the S-4 gathers fuel usage reports from all elements in the task force. The support platoon leader keeps the S-4 informed as to the status of the task forces' fuel carrying vehicles. Knowing the current availability of fuel in the task force, the S-4 incorporates knowledge of future planned operations and forms the task force's Class III

forecast (16:Chapter 8,20). The intent of the forecast is to provide the reaction time necessary to insure adequate fuel availability for the battalion's efforts. As a result, the S-4's forecast generally predicts fuel requirements for the following day's mission and the subsequent seventy-two hours (11:Chapter 5,9).

The battalion task force's Class III forecast forms the basis for the division and corps stockage levels. The brigade headquarters reviews and consolidates the forecasts of all of its organic and attached units. After consolidating the forecasts, the brigade S-4 section forwards the new forecast to the Division Materiel Management Center (DMMC). The DMMC in turn uses daily status reports from the Class III distribution points and the brigade S-4 forecasts to determine the division's bulk petroleum requirement. The divisional requirements are then forwarded to the Corps Support Command Materiel Management Center (COSCOM MMC) (11:Chapter 5,9).

The Corps Support Command Materiel Management Center evaluates the reports submitted by the subordinate divisions and directs a general support Petroleum Supply Battalion to ship the requisite quantities of bulk petroleum to the main distribution point at the DMMC. The bulk petroleum will be transported by either 5,000 gallon tanker trucks, 5,000 gallon railcars, or pipelines. Once the fuel arrives at the

DMMC, the division's Main Support Battalion assumes the responsibility of testing the fuel's quality, storing the fuel, issuing it, and distributing the bulk petroleum (15:Chapter 5,1-6).

From the main distribution point, the Main Support Battalion trucks the fuel to the Brigade Support Area (BSA) where the forward distribution point is located. At the forward distribution point the Forward Support Battalion assumes responsibility for storing the fuel, issuing it to the using battalion's support platoon leader, and distributing the bulk petroleum. Tactical units pick up bulk petroleum with their own organic refueling vehicles at the Class III distribution point in the BSA. If required by the tactical situation, the Forward Support Battalion's supply company may move fuel closer to the main battle area and establish a forward tactical refueling point (13:Chapter 5,1-13).

The bulk of the battalion task force's combat service support assets are under the direct control of the Support Platoon Leader. It is his responsibility to apportion the personnel and equipment under his control so as to provide each company team in the task force with the necessary support. The tank battalion has twelve Heavy Expanded Mobile Tactical Trucks (HEMTT). Under normal circumstances each company is supported by two HEMTT fuel carriers. As the

result of a tasking order that creates a tank-heavy task force, the Class III support assets of the organization would consist of ten M978 Heavy Expanded Mobile Tactical Trucks with a fuel capacity of 2,500 gallons each (30:Chapter 3,23) and one 5 ton truck fitted with two 600 gallon tank and pump units (30:Chapter 2,25). The Class III support for each of the tank companies normally consists of two Heavy Expanded Mobile Tactical Trucks while the infantry company is supported by the 5 ton truck. When necessary, an additional Heavy Expanded Mobile Tactical Truck will be allocated to support the infantry.

The task force service support assets are normally echeloned in two parts. The combat trains, located 2 - 4 kilometers behind the front line of troops, provides responsive support to the tactical forces. Class III assets located in the combat trains are generally limited to two Heavy Expanded Mobile Tactical Trucks; however, the tactical situation may dictate otherwise. The remainder of the task force's Class III assets are located in the field trains. The field trains are normally collocated with the BSA some 20-24 kilometers behind the front line of troops (16:Chapter 8,8-11). At the request of the company team first sergeant, the fuel trucks and other service support assets will move forward to link-up at a logistics release point. The first

sergeant then moves the assets forward to resupply the company team and its platoons (12:Chapter 7,6-10).

Motivation

In light of the forthcoming austerity, the Army is faced with the dilemma of having to do more with fewer resources. Only the most efficient application of resources will allow the Army to maintain deterrance in Europe and support the United States' commitments to security throughout the world.

Methodologies

Numerous techniques were investigated as to their relevancy as a methodology for evaluating the Class III resupply system that supports the battalion task force. Deterministic and stochastic methods were assessed for their potential to create a realistic, yet flexibile model,to be used to evaluate the battalion's ability to continually resupply itself with fuel. Methods with the greatest potential are:

1. Linear Programming.
2. Dynamic Programming.
3. Network Analysis.
4. Markov Process.
5. Simulation.

Each of these techniques will be reviewed below.

Linear Programming. Recognition that the Class III resupply system involved the assignment and distribution of a limited number of resources served as the starting point to evaluate potential methodologies. Typically, allocation problems are structured so as to minimize or maximize some function through the efficient allocation of scarce resources. The objective in this instance would be to maximize the number of continuous battalion combat hours before a platoon runs out of fuel.

Allocation problems are frequently solved using mathematical programming techniques. The first such technique to be examined was linear programming. Linear programming relies on a mathematical model of the real world situation to determine the appropriate solution to the problem. If the mathematical representation is to be accurate, then the real world problem must satisfy three important properties. These essential properties are proportionality, additivity, and divisibility. Proportionality implies that the value of each term in the objective function and the constraint functions is proportional to the value of the decision variable appearing in that term. More simply put, there are no returns to scale. To illustrate, the direct effect of doubling the inputs, in this instance fuel trucks, is the doubling of outputs, say the number of gallons of fuel hauled per day. Additivity is the requirement that the total value

of the objective function, or any constraint function, must be equal to the sum of the terms resulting from each decision variable. The property of divisibility requires that the decision variables can be divided into any fractional level desired. This means that noninteger values of the decision variable are permitted (33: 68-70).

The combined effect of these properties is to insure that the problem is in fact linear. The very nature of the resupply system to be modeled causes it to violate each of the three properties. Because of the nature of combat and the attrition that accompanies it, doubling the number of trucks does not imply a matching increase in the amount of fuel hauled. Thus the stipulation of proportionality is violated. The requirement for additivity is also violated in that the amount of fuel that can be delivered is a function of not just the decision variable but also the mission profile of the unit, location of the unit, and trafficability of terrain between the resupply point in the BSA and the platoons to be refueled. And finally, divisibility is not satisfied because reality precludes assigning portions of trucks to battalions in the Table of Organization and Equipment. This final property can be surmounted through the usage of integer programming; however, the violation of the first two properties also precludes the use of integer programming.

Assumptions can be made to simplify the nature of the real world situation and make it mathematically tractable to the linear programming approach. In so doing all functions of combat are assumed to be linear and simple proportion becomes the measure of things. Koopman cautions against such a procedural approach. His point is that the magic power of such an assumption is that it reduces many of the most difficult analytical problems to extremely simple ones with a two minute solution (23).

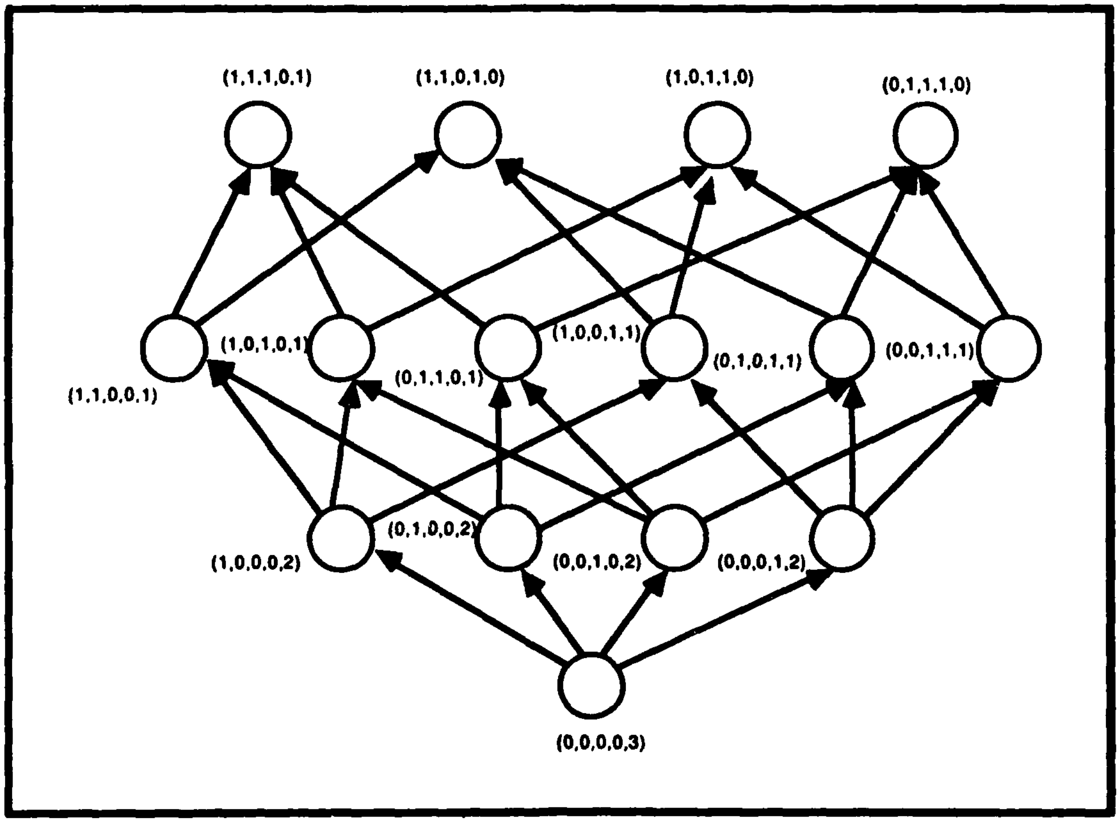
This is precisely the pitfall that occurs in an analysis provided as part of a Logistical Impact Study. The focus of this study was to determine the changes to current logistical requirements necessitated as the result of fielding improved Abrams systems. The analysis in the area of fuel resupply was based on the presumption that the current allocation of twelve resupply vehicles was adequate to support the battalion task force. Further, it was assumed that the original twelve fuel vehicles accurately reflected the desired tactical fuel transport capability of the battalion. It included no excess. The Army Modernization Information Memorandum updated the miles per gallon fuel factors for the M-1 and its product improved version, the M-1A1. When the new factors were placed in juxtaposition with the original factors, an increased requirement was developed as a percentage of the original M-1 consumption rates. A corres-

ponding increase was applied to the desired one time fuel haul capability of the tank battalion. This proportional approach to the problem was completed by dividing the one time fuel haul capacity by the capacity of the fuel haulers. The resulting quotient was accepted as the number of fuel haulers required by the battalion to maintain continuous operations (26:Appendix 15).

Dynamic Programming. Dynamic programming is another mathematical programming technique that is frequently used to create a mathematical model of a real world situation. In order to apply the dynamic programming technique to a problem, the problem must be formulated into stages with a policy decision required at each stage. Each of the stages must have a number of states associated with it. The states represent the various possible conditions in which the system might be at that stage of the problem. The effect of the policy decision made at each stage is to transform the current state into a state associated with the next stage (21:336-338).

The modeling of the Class III resupply system lends itself to this type of formulation. The stages would represent different phases of the battle or operation while the states of each stage characterize various possible network configurations of Logistic Release Points and unit resupply points resulting from different Class III requirements of

the battalion. The transition from stage to stage would accrue certain costs based on vehicle capacity, travel time, decreased effectiveness as a result of moving and attrition. Levin and Morgan suggest representing the system as a hypercube. See Figure 1 (25:828).



(24:44)

Figure 1. The Dynamic Programming Hypercube

This type of approach would require all of the refuel trucks to be initially located at the BSA. The BSA would thus represent the source node in the system. As the battle

progressed, the refuel trucks would be deployed forward along the edges of the hypercube, in order to support the vehicles in combat. The edges of the hypercube represent the costs associated with moving the refuel assets and their ability to support the tank force. As the battalion operation progressed from stage to stage, the hypercube would change. Levin and Friedman develop this methodology more thoroughly in their article "Optimal Deployment of Logistics Units in Dynamic Combat Conditions" (24:41-45).

Levin and Friedman suggest that combat is a dynamic process and can be broken down into stages for evaluative purposes. The theory of dynamic programming as the fundamental theory for optimization of multistage decision making has a certain validity. The drawback to using dynamic programming is referred to as the curse of dimensionality. The solution space tends to increase exponentially as the number of variables (stages and states) increases arithmeticly. The number of computations can be reduced to make the problem mathematically tractable through the use of simplifying assumptions. Each simplifying assumption incorporated in the formulation of the problem moves the model further away from the reality that it should represent and as a result could negate the validity of the research being performed.

Network Analysis. An other possible methodology for modeling the Class III resupply system is networking. Such

a technique requires the use of arcs and nodes to represent the real world flow of fuel (See figure 2). The nodes in the system represent the places where fuel is distributed. This distribution is analagous to the assignment of fuel to trucks or units such as platoons or even the attrition of

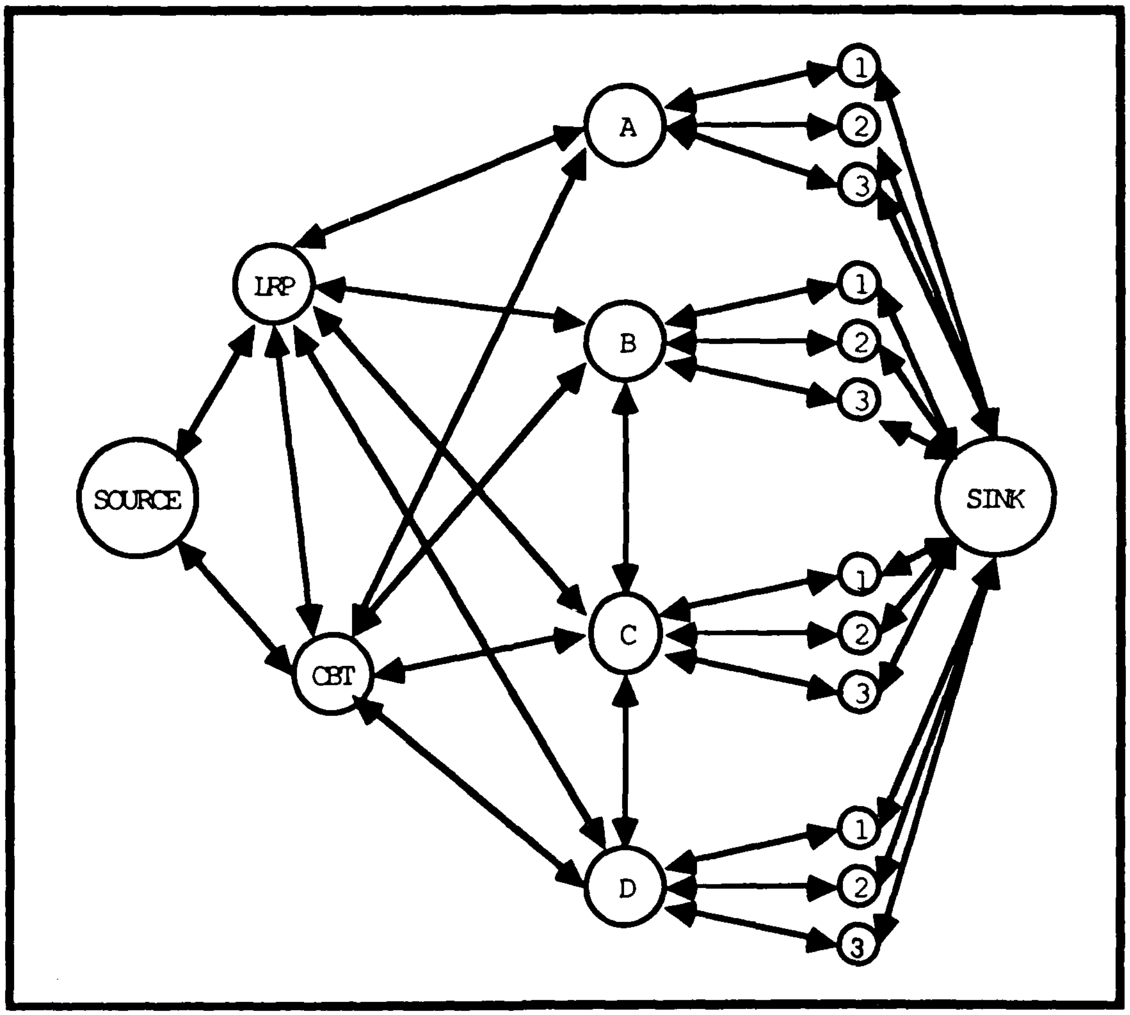


Figure 2. Battalion Resupply Network

fuel by the using vehicles. For example, the intermediate

nodes represent the BSA, LRPs, company team trains, and the platoon battle positions where resupply will be conducted. Two additional nodes need to be added to the system: an initial node to represent the initial source of fuel entering the system and a final node to represent the consumption of fuel. The arcs in the network represent the paths along which fuel flows from node to node through the system. Associated with each arc is a capacity. The capacity of the arc is a function of the distance between nodes, vehicle capacity, and fuel transfer rates.

There are several problems associated with using the network analysis approach to the problem. The network approach cannot address the problem in its entirety. The use of networks to trace the flow of fuel forward from the BSA along specified routes to the LRPs, and again forward to the unit combat trains is fine if several simplifying assumptions are made. Up to this point the focus is on the actual flow of fuel. Significant problems are encountered from this point forward because the point of focus and the battlefield change dramatically. After the fuel moves forward of the unit's combat trains, the focus shifts to the actual refueling of combat vehicles. The amount of fuel consumed by each vehicle and the probability of the vehicle surviving to be refueled introduce a random nature to the deterministic model. This stochastic nature of the battlefield

makes it difficult to accurately model the actual resupply phase of the system with a network model (29:15-17).

The second major problem is that several different networks would have to be constructed. Each network would represent a different tactical scenario; attack, defend, and delay or retrograde. The geometries of the various networks could be altered to investigate the nature of the relationships of various elements in each of the systems. From such an analysis of relationships, it might be possible to construct a generalized model that is not scenario specific, yet is accurate and can be used to conduct analysis (29:15-17).

Markov Process. Each of the techniques examined as potential methodologies has been deterministic in nature; that is to say that there exists a unique solution set for each specific set of inputs. There is no randomness associated with the process. The selection of a deterministic methodology implies that the fundamental assumption of the modeler is that combat is predictable in nature. Most students of military history, soldiers in service of their country, and war veterans would be hard pressed to find reality in such an assumption. Several stochastic processes allow for some of the randomness of reality to become part of the methodology. The Markov process is one such stochastic technique.

An analysis of the battalion Class III resupply system for the J-series tank and infantry companies determined the probability that a platoon would run out of fuel. Bettencourt modeled the Class III resupply system as a Continuous Transaction Markov process. As the arrival rate, he chose the rate at which the company's three platoons consumed fuel. The rate was determined to be a function of the platoon's total fuel capacity, expected number of miles traveled, expected number of operational hours and the vehicle's fuel consumption factors. The service rate, the rate at which platoons can be refueled, was determined to be a function of the distance between the resupply point and the element to be refueled, parameters associated with the rate at which the fuel vehicles could be refueled and how quickly the fuel vehicles could return to the battle area (1).

The steady state rates, as calculated by Bettencourt were predicated upon the assumption that the platoons would not be refueled until the combat vehicles were empty. Realizing the impracticality of this assumption, Bettencourt reworked the problem after changing the refuel rule. The new problem allowed for the refueling of fighting vehicles when they were at the half or two-thirds empty states. This real world touch forced Bettencourt to expand the number of states used in the Markov process. He now had a two dimen-

sional state variable which resulted in the consideration of multiple arrival and service rates. Later, Bettencourt used a multiple arrival and service rates as input to a model that yielded steady state matricies as output. The solution equations from these matricies provided joint steady state probabilities that a platoon would run out of fuel.

Bettencourt's selection of a stochastic process as a methodology for evaluating the resupply of combat elements introduces some of the uncertainties of the battlefield to the problem. However, it is not without inherent flaws. The continuous transition Markov process assumes that both the arrival and service rates are uniformly continuous. This assumption is an abstraction of reality. The service rate or rate at which fuel is consumed by the platoons is relatively continuous, though some what skewed, as the result of time in battle. The service rate or fuel resupply rate is by no means continuous. It is a discrete event that normally occurs as the result of coordination after the battle.

Simulation. Each of the techniques investigated thus far provides a closed form solution to the problem. If the assumptions utilized to generate the model remain unchanged and the input parameters remain the same, the same answer will be generated. The rigidity of such mathematical models fails to account for the completely random outcomes

that do occur on the battlefield. These random outcomes are the result of such nonquantifiable factors as the element of surprise, leadership of the commanders, the troops morale, or even the effects of weather. As such, these methods really are not the best and another approach is sought.

Simulation involves the construction of a mathematical model that describes the operation of the system in terms of events involving individual components of the system. The model is divided into elements with predictable behavior and includes the relationship between these elements. It is the association of probability distributions with the occurance of event's that introduces the random outcomes likely to occur in combat situations. The use of simulation also allows for the performing of sample experiments on the model of the system to determine the significance of each factor (21: 797-781).

For these reasons simulation is frequently used by the military community to examine organizational and doctrinal issues. Several studies that developed models of real world combat service support systems were examined.

Maintenance will be a key factor on the high intensity, modern battlefield. The rapid return of damaged weapon systems to fighting units will enhance the combat power of those units. In 1985, Cassady, recognized that the maintenance system can make a significant contribution only if it

operates in a timely and efficient manner. He conducted a study entitled the Battlefield Vehicle Recovery Study (BVERS) (5). BVERS focused on the analysis of key factors influencing the recovery effectiveness of Abrams tanks in an armor battalion. Cassady recognized the randomness of the principle recovery factors and decided that a stochastic modeling approach would be appropriate. Because of the complexity of the vehicle recovery process, a simple formal model approach was foregone in favor of a small scale computer simulation model. The simulation was designed to model an European defensive battle scenario.

Cassady felt that a detailed representation of the recovery process required a model much more complex than a simple queuing system consisting of disabled vehicles as the customers and recovery vehicles as the servers. Because recovery vehicles provide the lift required to complete certain types of repairs in addition to recovery and extraction services, they provide essential services to customers other than just disabled vehicles. The BVERS model recognized that recovery and other maintenance functions compete for the services of the limited recovery resources. Therefore, it modeled recovery as a subfunction of the maintenance process.

The BVERS model, a low resolution computer simulation, was developed utilizing current doctrinal literature. Al-

though it represents the dynamic elements present in a combat environment, the closed queuing network fails to address one of the most basic properties inherent in combat, attrition. The model does not represent the destruction of maintenance resources as the result of combat. Another significant limitation of the model is that it does not simulate the degradation of maintenance resource capabilities as the result of equipment failures, nighttime operations, and human factors. Also, as the result of simplifying assumptions, the model does not represent recovery by like vehicles.

Harding and Manteuffel, developed a simulation and used it to conduct an analysis of the attack helicopter battalion's ability to rearm and refuel itself (19). The simulation model was well designed and included those elements over which the battalion exercises direct control as well as those elements beyond their purview that impact on operations. The simulation modeled interactions at the BSA to include the effect of other aviation battalions' resupply vehicles being serviced at the ammunition transfer point and fuel, Class III, resupply point. At the battalion assembly area, holding areas for full trucks waiting to move forward and conduct resupply and holding areas for empty trucks waiting to be convoyed back to the BSA to be refilled are also simulated. The model includes routines that simulate

appropriate activities depending on the current availability status of resupply vehicles when a resupply request is made. Three Forward Arming and Refuel Points (FARPs) are simulated.

The model is not without limitations. It makes no provision for weather, a significant factor in helicopter operations, NBC operations are not included and attrition is not modeled. The modeler's intent was to focus on the logistical system and analyze its ability to provide sufficient fuel and ammunition to the helicopter in order to sustain continuous operations. The modelers felt that forcing 100% availability of helicopters would provide the greatest stress on the resupply system. Realistically, during the course of combat operations both helicopters and resupply vehicles are subject to attrition. This attrition is the result of maintenance failures and combat losses. Each system operates in a different realm of the battlefield, only meeting at the FARP and because of the different natures of each environment, different vulnerabilities and capabilities of the vehicles, it is extremely unlikely that both portions of the system will decay at equal rates. The difference in attrition rates will produce additional stress on the system. In fact, significant strain may be placed on the resupply system if its vehicles are attrited faster than the helicopters.

The Mission Area Resupply Simulation (MARS) was developed by FMC Corporation to study combat service support issues associated with the resupply of a battalion sized element of combat vehicles (26:Appendix 20). The focus of the model is on the resupply of both fuel and ammunition to the battalion's combat vehicles. The resupply demand is a function over time of fuel consumption and ammunition expenditure of the battle's survivors. Resupply vehicles, extremely vulnerable to threat artillery and mortar fire, are subjected to attrition and simultaneously forced to satisfy the demand of the surviving combat vehicles.

The MARS model combines logistical and combat activities in an European scenario that has an Abrams (M-1A1) tank battalion defending against a threat regiment. The simulation tracks fuel consumed and destroyed in both combat and logistical vehicles. It also tracks the ammunition expended in battle and destroyed in combat vehicles, logistical vehicles, and supply caches. From this data two measures of effectiveness are generated: the number of on-line tank hours for the day and the number of resupply vehicles lost during the day. These two measures of effectiveness were used to compare alternative mixes of logistical support vehicles for the U S Army Armor School.

The MARS model was developed to study attrition-induced combat service support problems for the resupply of a bat-

talion sized element of combat vehicles. The application of attrition to the resupply vehicles as well as the fighting force is a realistic approach. The major stumbling point of the analysis is that it focuses on only a short segment of the defensive battle, the first twenty-four hours. The survivability of both combat and combat service support elements is a function of not just the vehicle's capabilities and vulnerabilities but also the crew's ability to learn and perfect techniques of survival. Survival learning starts as soon as the crew is exposed to combat but rarely is completed in a period as short as twenty-four hours. Therefore a valid point could be made for running the simulation over a longer period of time. Surely, an European battle scenario of longer that twenty-four hours will find tank battalions conducting missions other than the defensive. Each of these mission profiles is different and as a result stresses the logistic system in a different way. The constant changing of mission profile produces its own confusion and strain. Perhaps mission profile is a significant factor and should not be overlooked when deciding how to provision the fighting force.

Summary

After having reviewed five possible techniques to develop a methodology and several related type studies, it appears that simulation is the most viable technique for

developing the methodology. Simulation reduces the number of simplifying assumptions necessary to make the problem mathematically tractable and at the same time has the potential to incorporate the random nature of combat. The availability of special purpose computer languages facilitates the development of a mathematical model that adequately portrays the real world Class III resupply system. The prevalance of microcomputers in todays world coupled with personal computer versions of special languages enhance the flexibility of using a simulation model. It also reduces the costs normally associated with working on mainframes and gives the analyst responsive answers.

CHAPTER III

Methodology

There are a number of situations in today's world in which it is useful to be able to evaluate the processes of a complicated system without having to actually experience the system. The analysis of military forces preparing for and engaging in combat is one such system. Computer simulation is a methodology frequently employed for conducting this sort of analysis.

By definition a system is a "... collection of entities or atributes which interact with each other and with the environment in an attempt to achieve a goal" (20:Chapter 1, 1). A model of a real system is an attempt to depict the elements of the system, their actions and their interrelationships. The representation created by the model does not perfectly replicate the actual system. Even in the best of models, this is so. Models often deviate from reality for one of two reasons: the purposeful omission of insignificant features or the simplification of complex issues that cannot be represented in any other way. Determination of whether or not a model is a valid representation of a system depends not only on the structure of the model but also on the intended purpose of the model (20:Chapter 1, 2-4).

The determination that simulation is the most viable technique for conducting analysis of the tank battalion's ability to continuously execute assigned missions, unimpaired by the tank's fuel consumption, serves as the point of departure for the development of a methodology. The intended purpose of the model and the nature of information required of the model should serve to mark the pathway for developing the methodology. Examination of these two issues will serve to raise several important issues that must be addressed as the simulation's methodology is formulated. The answers to these questions, while addressing subsequent issues, will tend to focus attention on the selection of an appropriate solution in each instance.

First, the model must to provide the user with a simple but effective tool that can be used to conduct analysis of the battalion's Class III resupply system. As the Mission Area Analysis proponent for the Close Combat (Heavy) Force, the Armor Center has the responsibility for insuring that the present tank battalion's organization is capable of sustained combat operations. The Armor Center is also responsible, under the Concept Based Requirements System, for projecting future requirements to support the conceptual needs of the battlefield of the future. The ability to serve both purposes necessitates that the model be extremely robust. Secondly, the model should be able to address the sensitivity of the Class III resupply system to the attri-

tion of both the combat forces and the resupply vehicles. It should also address the operational constraints inherent in combat between modern day forces.

Level of Resolution.

A primary consideration in developing the methodology is the selection of the level of resolution. Several options are available, each has its inherent advantages and disadvantages. One possible choice is to structure the simulation using a high resolution land combat model. High resolution models are traditionally used to model military forces at battalion and company level. The modeling is extremely detailed since individual soldiers and weapon systems are represented in the simulation. Because individual weapon systems and soldiers are modeled, an accurate audit trail is established for each element. This audit trail allows the analyst to follow each element through the battle from the start of the simulation to the termination of either the element or the simulation. Primarily, as the result of this detailed audit trail, each elements' interactions with other elements can be examined to determine interrelationships. An alternative is to develop the simulation using a low resolution land combat model. Low resolution models allow the modeler to aggregate elements into units of the modeler's choice. Frequently this technique is employed to model large scale elements such as divisions and corps by aggregating individual elements into

company or battalion sized units. The result of this aggregation is the loss of detailed information about individual elements that was provided by the high resolution model. The low resolution model creates an audit trail sufficient for the purposes intended. Whereas the high resolution model relies on the stochastic nature of events in determining outcomes, the low resolution model is deterministic and uses expected value computations to determine outcomes. Taylor contends that, in theory, enough replications of a stochastic high resolution will provide results similar to the expected results of the deterministic low resolution model (29:3,47) .

Still another method is the mixed model. This method combines the various advantages of high and low resolution. Models of this type may have some portions that are deterministic in nature while others are stochastic. Often in these types of models, the level of detail used to depict entities changes depending on the process. For example, the process of attrition may be represented as a one-on-one process while the process of movement may be aggregated to the battalion or brigade level (7:26-28).

In developing the methodology the needs and capabilities of the intended user are of paramount importance. If the developed methodology is to be implemented, it must be realistic, provide results supported by an audit trail, be easy to understand and implement, provide quick solutions

and provide a robustness that enables it to be modified and applied to alternative scenarios. To satisfy these requirements, a mixed resolution simulation structure was selected. The result of this choice is a simulation that provides a sufficiently detailed audit trail of a realistic scenario. It can be run on a micro computer, and is extremely robust. The model's robust nature is attributable to the synthesis of the SLAM II simulation language and the FORTRAN programming language. SLAM II forms the basic network that structures the resupply system. This network serves as the skeletal structure while the FORTRAN interfaces provide the muscles that hold the simulation together. The user's interface, all of the parameters required to run the program, and the refuel and attrition routines are programmed in FORTRAN.

In a general sense, the model is intended to be predictive. It is a hybrid cross of an analytic model and a Monte Carlo simulation. The focus of the model is to induce attrition related stress on the Class III combat service support system and to observe the outcome. The scenario used is a long term, 180 day war, set in an European environment. Attrition is applied deterministicly means to the primary consumers of fuel and the fuel resupply vehicles. The consumption of fuel is also modeled deterministicly. In order to introduce the variability of performance commonly observed in combat, thereby representing the 'realism' of

the situation, several other processes were modeled stochasticly. This use of deterministic and stochastic techniques resulted in a mixed model.

Lanchester Equations.

As mentioned above, attrition to vehicles and fuel consumption were modeled deterministicly. The attrition of the tank battalion is modeled using classical Lanchester theory. Lanchester's laws of modern combat are expressed in terms of the following differential equations:

$$dX / dy = - a * Y \qquad dY / dt = - b * X \tag{1}$$

$$dX / dt = - a * Y * X \qquad dY / dt = - b * X * Y \tag{2}$$

where

X = the number of X-type weapons at time t

Y = the number of Y-type weapons at time t

a = the rate at which a single Y-type weapon kills an X-type weapon

b = the rate at which a single X-type weapon kills a Y-type weapon

Equations at (1) represent Lanchester's Linear Law which assumes that all targets are visible to all firers (aimed fire) while equations at (2) represent the Linear Law which assumes that no targets are visible (area fire). As presented, these equations apply to homogeneous forces; forces comprised of one type of weapon system on a side. Modern combat requires combined arms operations to seize and maintain an advantage over the enemy. Equations (1) and (2)

do not apply to the representation of such heterogeneous forces. To deal with the problem of allocating the different types of weapons systems to different types of targets, Lanchester's equations have been generalized as:

$$dX_i / dt = - \sum_j c_{ij} * W_{ij} * Y_j \qquad (3)$$

where

X_i = the number of i-type X-elements at time t

W_{ij} = the percent of j-type Y-elements engaging target X_i at any time

c_{ij} = the inherent kill rate of j-type Y-elements against i-type X-elements

Y_j = the number of j-type Y-elements at time t

Similar results apply to the attrition of Y_j; however, that is not germane to this paper and is therefore omitted.

Vehicular Attrition. For the methodology to be predictive in nature and be sufficiently realistic to be used as a decision tool, it must address the attrition of tanks and HEMTT refuel trucks. Lanchester's equations, a deterministic approach, are considered to be the standard for force-on-force attrition models. Frequently, Lanchester's equations are represented as difference equations. The difference equations express the number of vehicles surviving at the end of a period of time as the difference between the number at the begining of the period minus the number destroyed during the period. The attrition of tanks

and HEMTTs is modeled using equations (4) and (5) respectively.

$$X_t = X_{t-1} - a * X_{t-1} \quad (4)$$

$$X_h = X_{h-1} - b * X_{h-1} \quad (5)$$

where

X_t = the number of surviving tanks at the end of the period

X_{t-1} = the number of tanks that started the period

a = the rate that tanks are destroyed by the enemy

X_h = the number of surviving HEMTTs at the end of the period

X_{h-1} = the number of HEMTTs that started the period

b = the rate that HEMTTs are destroyed by the enemy

Fuel Consumption. Recognizing certain parallels between the attrition of equipment by the combat process and the consumption of fuel by vehicles, Lanchester's equations were used to model the battalions' consumption of fuel. In the most general sense, fuel consumption is a function of whether the vehicle is idling or moving. If moving, the speed and type of terrain have a profound effect on the level of fuel consumption. Realizing that fuel is consumed in several different ways, the consumption seemed to be quite similar to the process of combat between heterogeneous forces. The situation to be modeled fit both of the underlying assumptions of hetrogeneous attrition: the effects

were additive in nature and the rate of fuel loss was proportional to the number of vehicles consuming the fuel. Once the coefficient of attrition was determined, fuel consumption was modeled using a difference equation similar to equations (4) and (5).

Stochastic Processes

Not all of the processes were modeled deterministicly. Besides the ever present element of possible attrition, all vehicles on the battlefield are subject to becoming non-operational as a result of mechanical failures. Because the difference equations accounted for only the vehicles categorized as catastrophic kills, vehicles that are non-operational for reasons of repair or recovery have to be accounted for through other means. These vehicles are recovered from the battlefield, repaired, and returned to battle. Vehicles that become non-operational during the course of operations influence the resupply system and therefore must be accounted for in some manner.

The number of vehicles surviving the day's combat activities serves as a starting point for determining how many tanks and refuel trucks arrive at the designated refuel points. The product of these numbers and the associated expected operational readiness rate is used as the mean value for a distribution function. In the case of the HEMTT vehicles an additional factor, a human factor, is made part of the product. This factor discounts the number of trucks

that actually arrive at the designated refuel point. It considers the possibility that the driver, a young enlisted soldier often operating by himself, gets misoriented, stuck, or has a maintenance failure in route to the refuel point. The tank often experiences these same problems but has more assets with which to overcome them. The fact that the tank crew is composed of four soldiers and the relative proximity of other tanks to assist with problems of this nature are the reasons that a human discount factor was not applied to the tank fleet.

The number of vehicles that arrive at the refuel point is modeled as a Binomial distribution because each vehicle's status is the outcome of a Bernoulli trial. This model determines the number of trucks and tanks that arrive at the refuel point by rounding the number of operational vehicles to the nearest whole number and conducting an individual Bernoulli trial for each vehicle. The sum of those trials which meet with success is compared with the number of operational vehicles. To insure that no more than the number of operational vehicles arrive for any one refuel operation, the minimum of the two numbers is selected as the number of vehicles to actually arrive at the refuel point.

Measure of Effectiveness

Since the crux of the problem was whether or not the tank battalion could sustain continuous operations, the measure of effectiveness was clear. The need for a predictive model implied that the examination of the issue had to be prospective and not retrospective. The measure of effectiveness had to reflect the ability of the battalion to provide enough fuel to sustain itself until the next refuel operation. The realization, that the amount of fuel that the tank battalion had the capacity to accept during refuel operations was a limiting factor, became the guide to selecting the measure of effectiveness.

The amount of fuel, after refuel, on board any one tank in the battalion was selected as a surrogate for the battalion's ability to conduct continuous operations because it represented the total assets available to get the battalion to its next refuel point. This measure was defined to be the minimum of two different values, either one of which had the potential to be the limiting factor. As mentioned above the amount of fuel received by the battalion is limited by the capacity of the tank to accept more fuel. Most often this is the case, but at some point in time, the number of refuel trucks is reduced to the point that they can no longer provide a full tank of fuel for every vehicle. At this point the average amount of fuel resupplied to each tank in the battalion becomes the critical element.

Assumptions

The decision to aggregate individual tanks, platoons, and companies into battalion sized elements necessitated that several assumptions be made. The first assumption is that all fuel resupplied to the battalion is distributed uniformly to each tank. This assumption has the appearance of being quite utopian; but it is current practice that when a shortage exists, fuel is distributed in a manner so as to cross level the battalion's assets. In practice, this procedure has had mixed results. The benefit of this assumption is that the battalion can be considered in the aggregate and fuel levels can be monitored by observing the level in any one operational tank.

Closely associated with the above is the assumption that all surviving tanks, with the exception of those being repaired at a maintenance point, consume fuel at the same rate. This assumption also implies that tanks are refueled after being repaired and rejoin their unit at the same level as the other tanks operating in the unit. Because of these first two assumptions, Lanchester's equations are used to model the fuel consumption of the battalion.

Several other assumptions were made about the start of the battle and how resupply would be accomplished during the battle. Initially, the battalion starts the battle with all of its vehicles operational. Once the battle begins these vehicles are subjected to attrition without replacement. At

the start of combat operations each vehicle's fuel tank is full. For planning purposes, each tank maintains a safety level of 50 gallons of fuel. This reserve is set to insure that the unit always has the assets required to execute a quick change of mission that requires a rapid shift of forces to apply combat power at another part of the battle area.

In order to evaluate the ability of the HEMTT fleet to maintain the fuel level of the combat vehicles, an assumption was made that the BSA could supply all of the fuel required by the battalion to conduct continuous operations. The resupply of the scout platoon, mortar platoon, and other combat service and service support elements was not addressed. Many of these elements have the ability to refuel at the BSA in the battalion's trains. Several elements found forward in the battle area, such as the scout platoon, mortar platoon, and certain command and control elements, do not have this capability. The assumption was made that because these elements place a small demand on fuel, compared to the demand placed by the tank fleet, they could be refueled by dedicating two fuel tankers to their support. It was further assumed that these two vehicles would be sufficient to maintain the requisite fuel levels for these elements throughout the battle.

The Model

The model developed using the aforementioned methodology is basically a series of simultaneous difference equations. Instead of calculating the fuel consumed by the tank battalion during the period, the fuel consumption difference equation was transposed and used to schedule the subsequent refuel operations. The criteria for refuel was that all fuel, with the exception of the reserve, be consumed. This difference equation functioned as the event scheduling mechanism for the model. At the scheduled time for refuel, the difference equations for vehicle attrition determined how many tanks and HEMTTs survived combat during the ending time period.

Once the deterministic phase of the model ends, the stochastic process begins. The output from the deterministic portion of the model, the number of surviving vehicles, becomes the input to the stochastic portion. The Bernoulli distribution determines the actual number of vehicles to conduct refuel operations. Once the limiting factor has been determined the tanks are refueled and the fuel consumption difference equation schedules the next refuel operation.

Each refuel operation is monitored to insure that the limitation on the number of refuels is not violated. If the battalion should require more refuels than allowed during the day, the iterative process terminates and data is col-

lected. A separate portion of the model monitors the passage of time. At the completion of the day, it checks the number of refuels conducted and initializes the counter for the new day's operations. Should the battalion survive for 180 continuous days without running out of fuel, the event is noted and categorized as a success. At this point, either another iteration of the model is executed or the simulation is terminated.

CHAPTER IV

Demonstration of Methodology

Data for the Methodology

In order to test the adequacy of the methodology, through demonstration, input parameters for the model must be determined. Before Lanchester type difference equations can be applied, the attrition coefficients, a and b, for the tanks and HEMTTs respectively must be determined. The consumption coefficient, c, likewise must be quantified. The methods presented herein for determination of the coefficients is only one such way to determine the necessary input values. The user can use methods or sources of his or her own choice to generate the required parameters.

Vehicular Attrition Coefficients. Generally, attrition coefficients represent the rate at which an individual Y firer of type i destroys an X-target of type j. The modeling community is in agreement that the coefficient of attrition is equal to the inverse of the expected value of the time required for a Y-type target to acquire and engage an X-type target, T_{xy}. There is dissention as to how to measure T_{xy}. Bonder claims that it is range dependent and should be recalculated with each range change (3). Clark claims that it is scenario dependent and that it is

calculated correctly only by using output from a high resolution model (6).

In order to demonstrate the model, the assumption was made that the attrition coefficient is analogous to the rate that equipment in the theater of operations needs to be replaced. The Army's Concept Analysis Agency recently completed a classified study of war in an European environment (31). One of the outputs of the study was a set of replacement factors for various types of equipment. The replacement factors were grouped in 30 day increments from initiation of combat to battle termination at day 180. The study included data on the number of M-1 tank systems and the HEMTT type vehicles that were required to be replaced during the half year of combat operation.

The individual replacement rates used to demonstrate the methodology are representative of the rates in the study; however, specific data is not used for several reasons. First, the intent of the model is to provide an unclassified demonstration of the methodology, and secondly, for different reasons, the attrition factors of each system had to be altered. The study did not include the M-1A1 version of the Abrams tank; however, using professional judgement and personal experiences, a comparison of the data for the M-1 and M-60A3 tank systems was made and the attrition rate for the M-1 was altered to reflect the survivability improvements made to the new tank.

The replacement rates for the HEMTTs also required adjustment. Intuitively, one would think that vehicles that operate in the forward edge of the battle area are much more susceptible to attrition than ones in the rear area. The MARS model developed by FMC quantified this difference in survivability and developed some survivability factors. A review of the number of HEMTT vehicles involved with the study revealed that the battle started with almost three times the number of vehicles that are normally assigned to forward units. To account for the significant number of HEMTTs that are operating in the safer rear areas, the HEMTT attrition rate was increased. This new rate compensates the HEMTTs operating in forward areas for the increased risk that corresponds with their greater exposure to artillery and direct fire weapons.

Fuel Consumption Coefficients. The determination of fuel consumption coefficients in the heterogeneous case is somewhat more difficult than in the homogeneous case. Specifically, the consumption rate is no longer simply the rate that a single tank consumes diesel fuel but rather a function of how many hours the tank idles and how many hours the tank is operating in its three movement modes. The consumption coefficient becomes the product of the allocation factor, the percent of time that a tank is consuming fuel in a specific mode, say idling or moving

cross country, (W_{ij}) and the consumption coefficient, the rate that a tank consumes fuel while operating in that mode, (c_{ij}). See equation (3). Because the tank must be operating in one of the four modes to consume fuel, the sum of the consumption coefficients for each mode represents the overall rate that the tank consumes fuel, the consumption coefficient .

In the context of this problem, fuel is consumed by the tank battalion in one of four ways. It is consumed either by idling or movement (crosscountry, on secondary roads, or primary roads). Previous tests and studies have determined the rate at which a tank consumes fuel, the consumption factor (c_{ij}), for each of these four modes. A twenty-four hour combat mission profile for an European scenario is used to determine the percentage of time that the tank battalion is operating with that consumption level (W_{ij}). Because of the linear nature of the process the overall consumption rate can be determined quickly utilizing a decision tree and finding the expected value. The value was calculated to be 25.23 gallons per hour. As a check, this value was compared with the product of the current miles per gallon estimate for the M-1A1 and the daily expected number of miles traveled. The two values compared favorably.

Stochastic Processes. As discussed in Chapter III, the difference equations account for only the vehicles that are catastrophic kills and could not be returned to battle.

Vehicles that are being repaired, recovered, or temporarily non-operational for some other reason, generally do not consume fuel while in these states. Unlike the catastrophic kills, these vehicles will return to battle and create a demand for fuel. In order to realistically represent the system, the model must account for these demands.

The stochastic process representing these activities uses the vehicle's Operational Readiness (OR) rate as the starting point for the determination of how many vehicles actually arrive at the refuel point. The rates are adjusted slightly to reflect the durability of the vehicle in conducting continuous operations, the environment in which the vehicle must operate and a realistic approach to what would be considered an operational vehicle in a combat situation. In the case of the HEMTTs, the human factor applied to the OR rate was strictly subjective in nature. The model recognizes this and allows the user to change these parameters.

After determining the probability that vehicles would arrive at the refuel point, the parameters (n,p) for the Binomial distribution were selected. The number of vehicles alive, calculated by the difference equations, served as the input for the parameter n. Estimation of the parameter p was not accomplished as easily. Trial and error proved to be the method for determination of p; probabilities had to be selected such that, the minimum of the OR rate or draw

from the binomial distribution made intuitive sense. This selection of the minimum value was crucial because it would be unrealistic to expect more vehicles to show up at the refuel point than were operational.

Analysis of Output

Using the input just described, 250 replications of these different cases were made to determine the battalion's capability to support itself for 180 days of continuous combat. Each of the excursions examined the success of the battalion as it operated with a different refuel rule. Either one, two, or three refuels were allowed as the maximum number of daily refuel operations permitted.

One Refuel. When the battalion was limited to conducting a single refuel operation each day, it ran out of fuel on each of the 250 simulations. The longest that the battalion survived was just under three days. Intuitively this makes great sense. Consider an inventory type plot of instantaneous resupply of fuel at the critical point in time and from that point forward in time, the attrition of fuel at a constant rate (c_{ij}). The best case situation, under the assumption that the tanks are refueled to capacity at each refuel, has the curve converging twice on a single day by the close of day five. See appendix F. Once attrition is introduced to the system, the time between needed refuels is reduced as a result of the inability of the HEMTTs to

fill the tanks to capacity. Note the cumulative frequency distribution of failure times in figure 3.

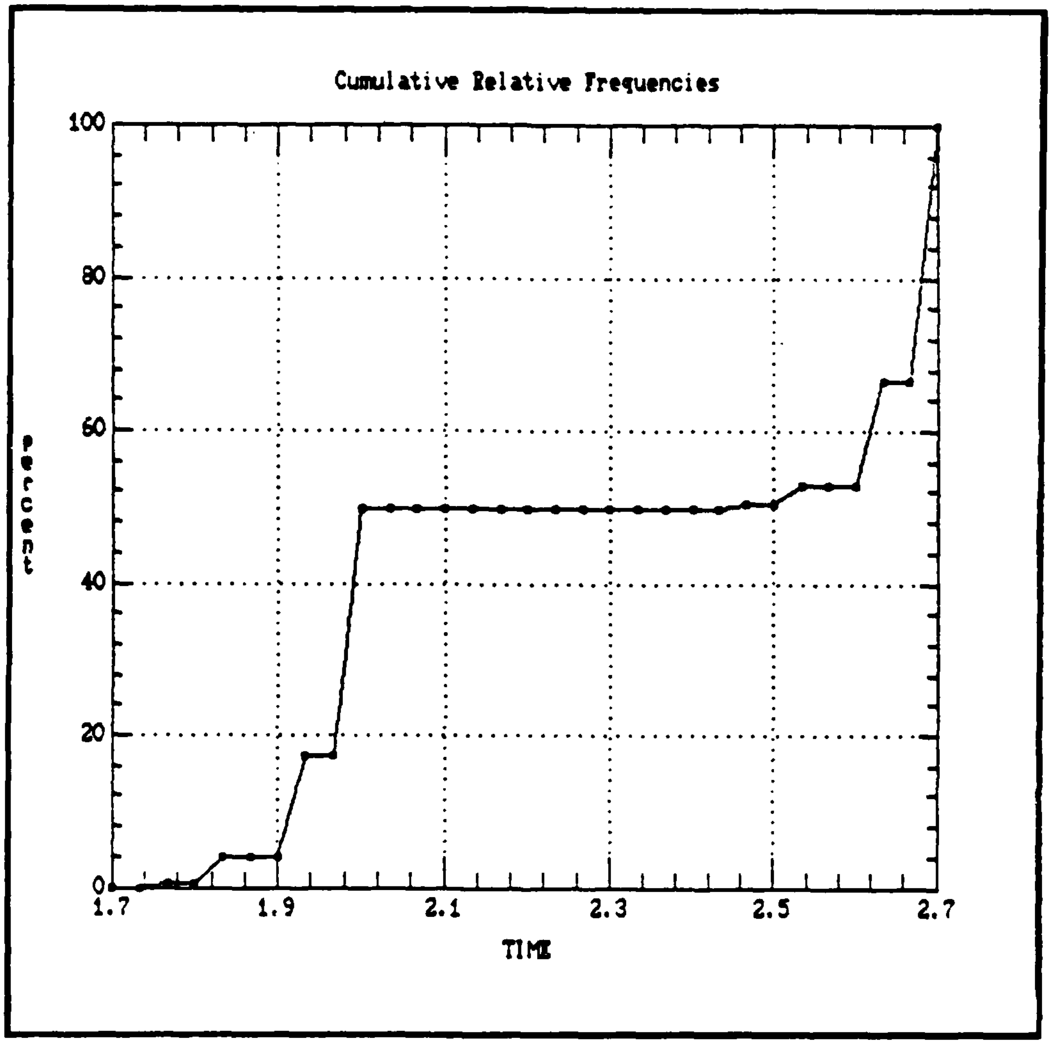


Figure 3. Frequency of Failure - One Refuel

Two Refuels. If the battalion is allowed to refuel twice a day, it still runs out of fuel before it can complete 180 days of operations. In fact, there is a significant trend for the battalion to run out of fuel within the first month of combat, see figure number 4. The

cumulative relative frequency plot in figure 4 indicates that if the battalion can survive the first month of combat, there is a good chance it will survive the second month before it runs out of fuel. This same figure shows that no battalion was able to conduct continuous operations for five complete months. Examination of the audit trail using the same inventory technique reveals that the number of operational HEMTTs is again the limiting factor.

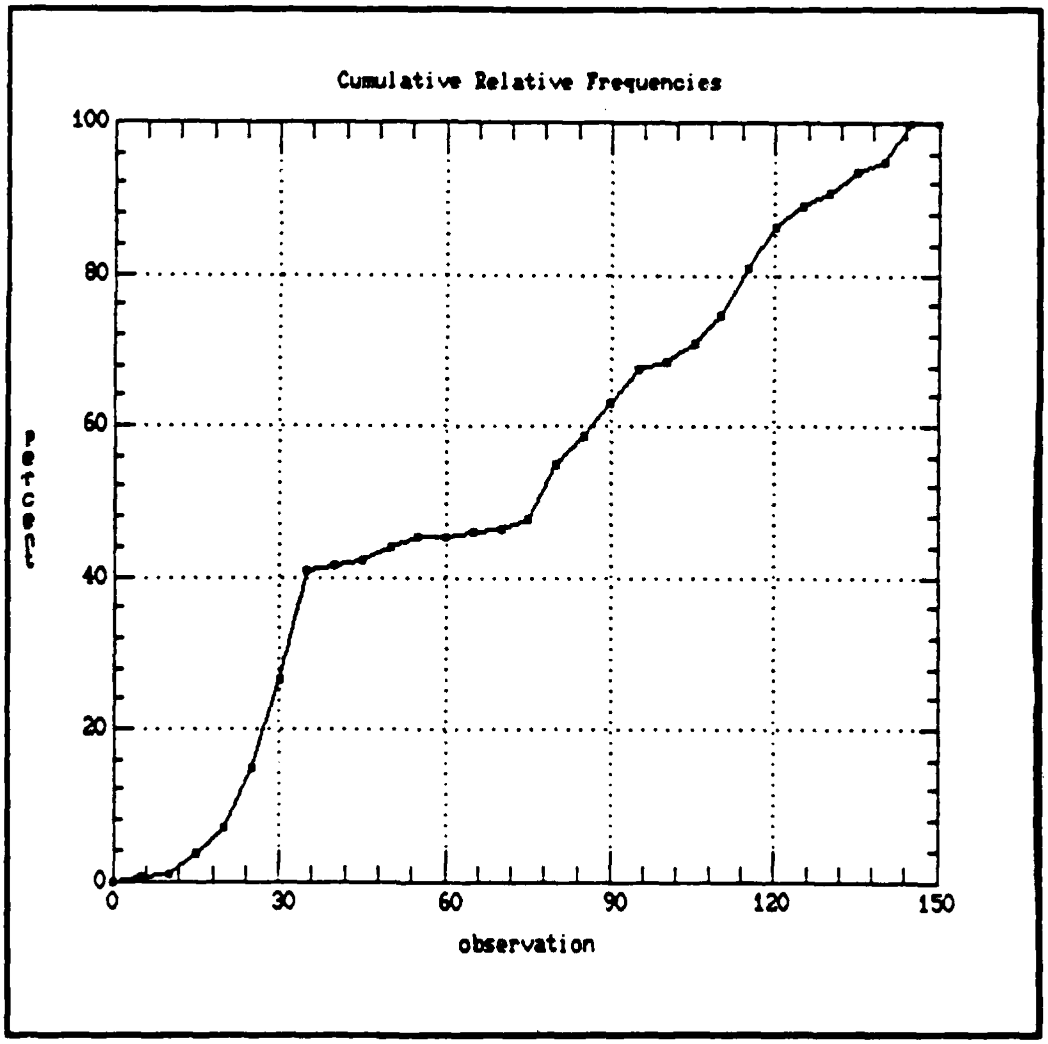


Figure 4. Frequency of Failure - Two Refuels

Three Refuels. Though the number of operational HEMTTs remains the critical factor, the ability to refuel three times a day significantly improves the success of the battalion. Approximately two thirds of the time, the battalion is able to maintain continuous operations for the duration. When it is not successful, ninety percent of the time it still conducts operations for 135 consecutive days.

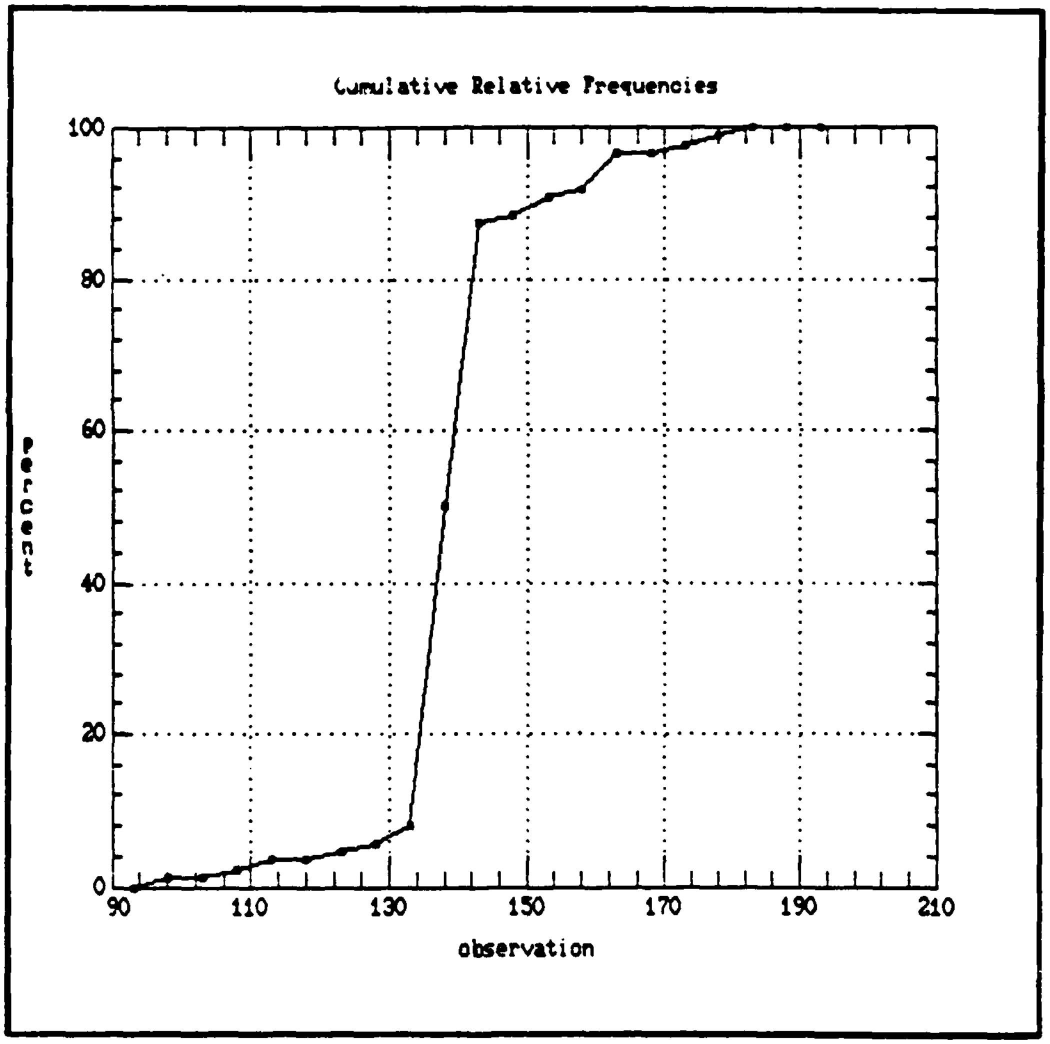


Figure 5. Frequency of Failure - Three Refuels

Distribution Fitting

For each of the three excursions, the results were fitted against known distributions in an attempt to identify a 'neat' probability distribution function. The number of samples was set at 250 for each simulation in an attempt to take advantage of the Central Limit Theorem. This high number of sample points precluded using the Kolmogorov - Smirnov for distribution fitting. The Chi-Square test was used to test the null hypothesis that the new distribution was of a certain known type. Hypothesized distributions included: normal, beta, gamma, weibull, chi-square, uniform, and others. In each instance, the test failed. The level of significance that had to be accepted inorder to accept the null hypothesis was extremely small. Thus the relative and cumulative relative frequency polygons remain as extracted from the data.

CHAPTER V

Results, Conclusions, and Recommendations

Results

Before the methodology, as demonstrated in this paper, can be accepted as a worthwhile approach to analyzing the problem, it must pass two critical tests: verification and validation. If the methodology can be neither verified nor validated, then it is worthless to the analyst and another solution must be sought.

Verification. Verification is the process of establishing that the model functions as intended. The SLAM simulation language provides a control statement that is invaluable to the verification process. The MONITOR statement allows the programmer to trace entities as they progress through the system. As a result, the programmer can examine the timing of the simulation, the sequencing of events, and the overall process of the simulation. Though MONITOR gives the programmer vision of the interworkings of the network portion of the simulation, it does not provide any insights to the occurances of events in the FORTRAN subroutines.

In order to gain an insight of the events as they occur in the FORTRAN segments of the simulation, an audit trail was created. The audit trail consisted of a timed tracing of the values of certain attributes and the intermediate

calculations of several parameters essential to the resupply process. Using the audit trail, the logical process of the model could be examined. Evaluation of the audit trail verified that the implementation accurately reflected the specified intent of the methodology.

Validation. Determining that the model performes as expected is not enough to accept the methodology. It must also be demonstrated that the model is a reasonable representation of the system that it is intended to recreate. This process is referred to as validation. Normally, validation is accomplished by comparing the model's results with what is experienced in the real world, but in the case of modeling combat systems this is impossible. Land combat modeling proves to be a challenge for validation. Often, the simulations and models are being conducted to evaluate the process of a system without having to experience it. In some instances historical data exists that can provide insight and be used to validate the model while other times, a combination of professional judgement and similar related experiences must be relied upon. In this instance, it was the later that was used. Professional experiences, in the European training environment, though attrition was only simulated, support the results of the methodology. Professional judgement of personnel in the Armor Center's Directorate of Combat Developments also supported the results of the methodology.

Conclusions

The methodology, herein developed, is designed as a decision support tool for analysis of force structure issues. The intent is to examine and provide insights on the tank battalion's ability to resupply itself with enough fuel so as to be able to conduct continuous operations for 180 days of combat. Based on the running of the model and an examination of audit trails produced, the methodology adequately represents the Class III resupply system. If more detail is required to answer questions about individual tanks or platoons running out of fuel, the level of resolution must be changed.

The methodology is extremely robust as a result of the simulation model's structure. With the exception of the fifty gallon fuel safety factor, the model relies on the user to input some or all of the initial conditions and parameters. Once determined by the user, the model's inputs can be uploaded from either a data file or the micro computer's key board.

Because the modeler has the ability to specify the inputs, there is great flexibility to analyze virtually any homogeneous force, whether current or conceptual. The scenario is not limited to European conflict. The analyst has the ability to develop different daily consumption rates depending on the expected mission profile and the terrain in the area. The analyst can quickly evaluate the impact that

a change in consumption rates (c_{ij}'s) will have on the sustainability of the force and generate a validated demand for additional resources to support the battalion.

The demonstration of the methodology serves to point out that the increased fuel consumption rate of the Abrams tank without a corresponding increase in fuel support capabilities has increased the probability that the battalion will run out of fuel early on in the battle. All of the enhanced weapons systems are for naught if the vehicle loses its ability to move on the battlefield. For the tank force, movement is survivability as well as a force multiplier.

Recommendations

The methodology developed in this research effort is a decision support tool that enhances the US Armor Center's ability to evaluate the Class III supportability of the tank battalion. It was demonstrated using the homogeneous force of a tank battalion. In the conclusions section it was mentioned that the methodology is equally applicable to the analysis of a mechanized infantry battalion or any other homogeneous force. Modern combat dictates that success on the modern battlefield mandates the use of combined arms. At the battalion level, this implies the formation of balanced and heavy task forces. The methodology applied to the homogeneous forces is equally applicable to heterogeneous forces. Minor changes to the FORTRAN subroutines and a few additional sections of code would expand the model's rele-

vancy to include heterogeneous forces. This expansion of the methodology would also allow the scout and mortar platoons and other elements to be explicitly represented in the model rather than their current implicit representation.

Numerous assumptions were made while developing the methodology. Additional programming efforts could reduce the number of assumptions. For instance, this model addressed an attrition-induced environment but assumed that there would be no resupply of vehicles. At some point during the battle, the battalion will be resupplied with either new equipment or equipment remaining from combat ineffective units. Lanchester's basic equations can be expanded to represent resupply by the addition of an additional term, the replacement rate.

The consumption coefficient was developed using a general European daily mission profile. A much more accurate consumption coefficient could be developed as the result of the investigation of the specific mission profiles expected to be employed in a particular theater of operations. Generally, one would expect that the percentage of time that the tank battalion consumes fuel in a particular mode (W_{ij}'s) is related to the specific mission being conducted. For example, the battalion would consume more fuel in the movement modes of an attack mission than in a defense mission.

Another major assumption that needs to be researched is the one that stipulates that the BSA is able to supply the battalion with all the fuel required to support continuous operations. In light of the Abrams' increased fuel consumption rates and the vulnerability of the BSA, several questions need to be answered. First, does the BSA have the assets required to haul and store the fuel demanded by the battalions it supports. The second question is important if the answer to the first is acceptable. How many refuels a day can the BSA support? It may very well be that the three refuels a day is more than can be routinely supported.

The final recommendation concerns Class V (ammunition) resupply. Class III and Class V resupply are closely related in that the trucks that ferry the supplies belong to the same family of vehicles (HEMTT). They depart from the BSA together in convoy and hopefully arrive at the unit to replenish consumed assets. Resupply doctrine attempts to resupply Class III and Class V simultaneously in order to minimize the combat unit's vulnerability. This methodology could be expanded to include Class V resupply. An improvement of this nature would allow analysis of the battalion's ability to maintain continuous operations and analysis on the compatibility of the two systems.

SLAM Program

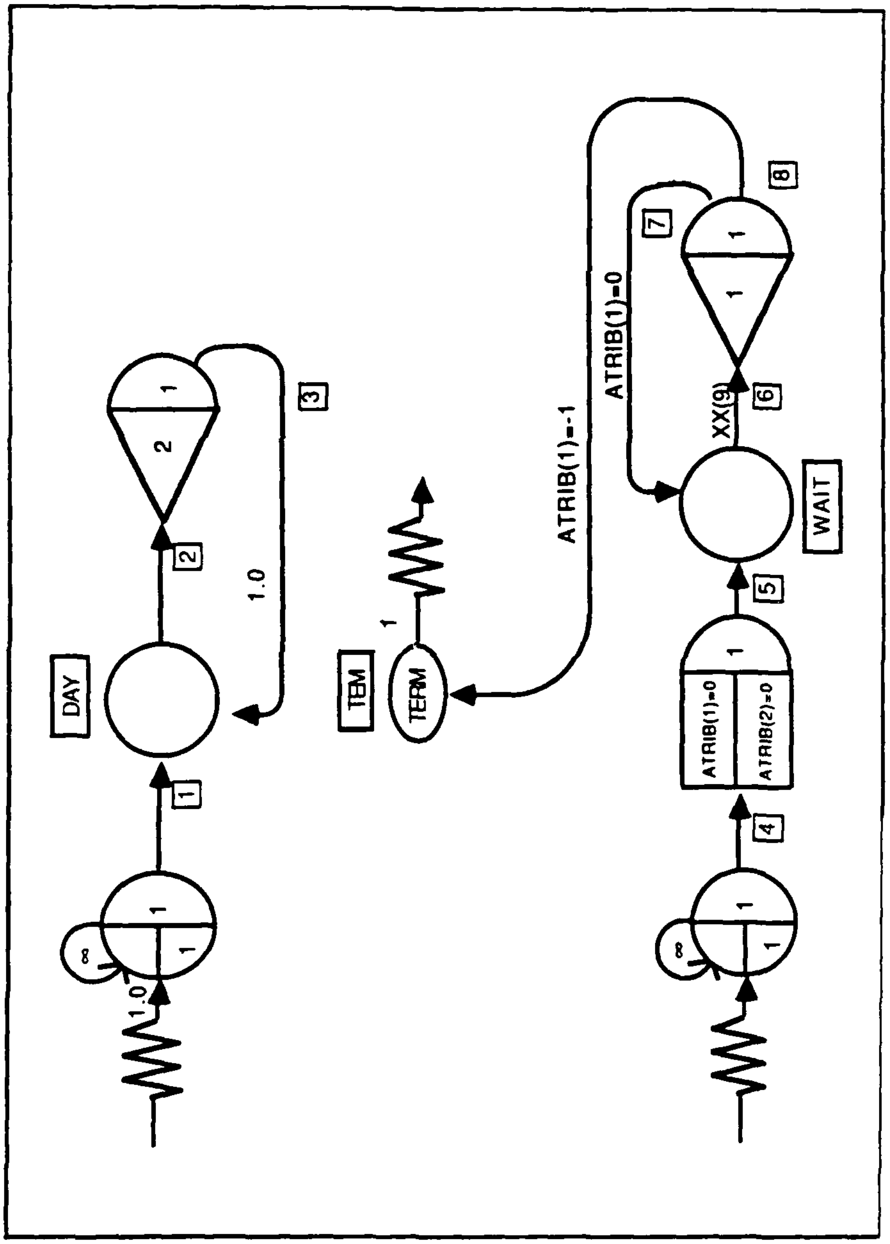


Figure 6. SLAM Network Model

Appendix A : SLAM Program

```
GEN,LANGHAUSER,LOW_RES_CLASS_III_RESUPPLY,11/26/87,250,N,N,,N,N,72;
LIMITS,10,10,20;
NETWORK;
;-----------------------------------------------------------------
;       TIMING SEQUENCE
;-----------------------------------------------------------------
        CREATE,,1.,,1,1;
           ACT/1,0.,1.,DAY;
DAY     GOON,1;
           ACT/2,0.,1.;
        EVENT,2,1;
           ACT/3,1.,,DAY;
;-----------------------------------------------------------------
;       REFUELING SEQUENCE
;-----------------------------------------------------------------
        CREATE,,0.,,1,1;
           ACT/4,0.,1.;
        ASSIGN,ATRIB(1) = 0,ATRIB(2) = 0,1;
           ACT/5,0.,1.;
WAIT    GOON,1;
           ACT/6,XX(9),1.;
        EVENT,1,1;
           ACT/8,0.,ATRIB(1).EQ.0,WAIT;
           ACT/9,0.,ATRIB(1).EQ.-1,TEM;
;-----------------------------------------------------------------
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;-----------------------------------------------------------------
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FORTRAN Routines

Appendix B : FORTRAN Routines

```
$INCLUDE:'PRCTL.FOR'

C*****************************************************************
C
C  This is the FORTRAN interface with the SLAM EXECUTIVE. All of the
C  subroutines are used for one of the following reasons:
C       -  interfacing with the user
C       -  calculating the next refuel point
C       -  opening and closing input and output files
C       -  printing audit trails to the output files
C
C*****************************************************************
      PROGRAM MAIN
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP, NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/USER1/AH(6), AT(6), TANK(3), RHEMTT(4), FCR, REFUEL, NRUN,
     1            NPTR, NNPRNT(5)

      NCRDR=5
      NPRNT=0
      NTAPE=7

C****open and close the output files

      OPEN(3,FILE='SIM.OUT', STATUS='NEW')
      OPEN(4,FILE='AGG.OUT', STATUS='NEW')
      OPEN(6,FILE='PLT.OUT', STATUS='NEW')
      WRITE(4,*)'     TERMINAL DATA FROM SIMULATION '
      WRITE(4,*)' '
      WRITE(4,*)' '
      WRITE(4,*)'  DAY    REFUEL      TANKS      HEMTTS'
      CALL SLAM
      STOP ' '
      CLOSE (3)
      CLOSE (4)
      CLOSE (6)
      END
```

Appendix B : FORTRAN Routines

```
      SUBROUTINE INTLC

C*********************************************************************
C
C    The purpose of this subroutine is to allow the user to input
C    data to the simulation. The user has the choice to initiate
C    the simulation by: - building a NEW configuration file
C                             -  set all parameters
C                             -  default the attrition coefficients
C                       - use an EXISTING configuration file
C                       - use DEFAULT values in the simulation
C                       - change mind and EXIT the simulation
C
C*********************************************************************

      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP, NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/USER1/AH(6), AT(6), TANK(3), RHEMTT(4), FCR, REFUEL, NRUN,
     1             NPTR, NNPRNT(5)
      CHARACTER*1 ATEST, DUMMY
      CHARACTER*12 FILENAM

      CALL BLANK
      IF (NNRUN .EQ. 1) THEN
       WRITE(*,*) ' Before the model executes, the user is reminded:'
       WRITE(*,*) '  '
       WRITE(*,*) '  '
       WRITE(*,*) ' 1) The number of simulations to be run is a user '
       WRITE(*,*) '    input but the maximum number allowed is 250. '
       WRITE(*,*) '    (this can be expanded -- see user guide) '
       WRITE(*,*) '  '
       WRITE(*,*) ' 2) The maximum number of audit trails is five and '
       WRITE(*,*) '    they must be specified in ascending order. '
       WRITE(*,*) '    This can be redimensioned -- see user guide '
       WRITE(*,*) '  '
       WRITE(*,*) ' 3) Output from each execution of the model is put '
       WRITE(*,*) '    in output files named SIM.OUT, AGG.OUT, PLT.OUT '
       WRITE(*,*) '    These files must be renamed or subsequent use '
       WRITE(*,*) '    of the model will overwrite the values. '
       WRITE(*,*) '  '
       WRITE(*,*) ' 4) Attrition coefficients for the tank and HEMTT '
       WRITE(*,*) '    are in thirty day intervals. The simulation '
       WRITE(*,*) '    will prompt six times for each vehicle type. '
       WRITE(*,*) '    The first prompt is for days 1 - 30 and the '
       WRITE(*,*) '    the final prompt is for the final 30 days of '
       WRITE(*,*) '    battle. '
       WRITE(*,*) ' Hit RETURN To Start The Model '
       READ(*,'(A)')  DUMMY
```

```
      CALL BLANK
      END IF

C****If this is the first run of the simulation

5     IF (NNRUN .EQ. 1) THEN
C****then initialize output array pointer
         NPTR = 1
         DO 6 I = 1, 5
            NNPRNT(I) = 0
6        CONTINUE
         CALL BLANK
C****prompt the user for the number of simulation runs to be executed
C****the maximum number is 250 but SLAM code can be increased in line
C****number 1 and additional seeds added at the end of the SLAM program

         WRITE(*,*) ' This Program is Limited to 250 Simulation Runs '
         WRITE(*,'(A\)') ' Enter  of Simulation Runs Desired: '
         READ(*,*) NRUN

C****user is prompted for the number of complete audit trails to be
C****saved. next prompt is for specification of run numbers. the
C****maximum number of runs is 5 but this can be changed by altering
C****the dimension of array NNPRNT just below line 5

         WRITE(*,*) 'Specify Number of Runs for Detailed Audit Trail:'
         WRITE(*,*) '    ***** Maximum of 5 Different Runs *****  '
         READ(*,*) N
         IF (N .GT. 0) THEN
            WRITE(*,*) 'Enter Run Numbers  --  in Ascending Order:'
            READ(*,*) (NNPRNT(I), I = 1, N)
         END IF
```

```
C****if yes
C****then prompt for values and read into the program and save to file

         IF (ATEST .EQ. 'Y' .OR. ATEST .EQ. 'y') THEN
            DO 25 I = 1, 6
               WRITE(*,200) I
               READ(*,*) AT(I)
25          CONTINUE
            DO 30 I = 1, 6
               WRITE(*,300) I
               READ(*,*) AH(I)
30          CONTINUE
            WRITE(2,*) (AT(I), I = 1, 6)
            WRITE(2,*) (AH(I), I = 1, 6)
         ELSE

C****if no
C****then save the default values to the configuration file
C****     read in the default values at line 20

            WRITE(2,*) .0091, .0088, .00152, .0005, .00021, .00018
            WRITE(2,*) .00552, .00638, .00518, .00428, .00084, .00070
            GO TO 20
         END IF
         GO TO 15
      END IF
```

```
C****user specifies which option is to be used to start the simulation
WRITE(*,*) '   *****  SIMULATION OPTIONS  *****'
         WRITE(*,*) ' '
         WRITE(*,*) '   1 - Build a NEW Configuration File'
         WRITE(*,*) '   2 - Use EXISTING Configuration File'
         WRITE(*,*) '   3 - Use DEFAULT Values'
         WRITE(*,*) '   4 - EXIT'
         WRITE(*,'(A\)') ' Enter desired option number: '
         READ(*,*) NOPT
         CALL BLANK
         IF (NOPT .EQ. 1) THEN

C****if the user's choice is to build a new configuration file
C****then open and name the file
C****     prompt for values at line 10

            WRITE(*,'(A\)') ' Enter NEW Configuration File Name: '
            READ(*,'(A12)') FILENAM
            OPEN(UNIT=2, FILE=FILENAM, STATUS='NEW')
            GO TO 10

C****if the user's choice is to use an existing configuration file
C****then open the file and read in the data
C****     start the simulation at line 15

         ELSE IF (NOPT .EQ. 2) THEN
            WRITE(*,'(A\)') ' Enter EXISTING Configuration File Name: '
            READ(*,'(A12)') FILENAM
            OPEN(UNIT=2, FILE=FILENAM, STATUS='OLD')
            READ(2,*) (TANK(I), I=1, 3)
            READ(2,*) (RHEMTT(I), I=1, 4)
            READ(2,*) FCR, REFUEL
            READ(2,*) (AT(I), I = 1, 6)
            READ(2,*) (AH(I), I = 1, 6)
            GO TO 15

C****if the user choses to use default values
C****then read in the values at line 20

         ELSE IF (NOPT .EQ. 3) THEN
            GO TO 20

C****if the user changes mind and decides not to run the simulation
C****then stop the program

         ELSE IF (NOPT .EQ. 4) THEN
            STOP
         ELSE
```

```
C****if the user enters an unexpected reply
C****then call the error subroutine and prompt the user for a choice

            CALL ERR
            GO TO 5
         END IF

C****if the user's choice was option number 1
C****then prompt the user for data required to run the simulation
C****     read in the data input by the user
C****     save the data by printing the to the configuration file

10       WRITE(*,*) ' Simulation Data Initialization'
         WRITE(*,'(A\)') '     Enter Initial  Tanks: '
         READ(*,*) TANK(1)
         WRITE(*,'(A\)') '     Enter Tank Fuel Capacity: '
         READ(*,*) TANK(2)
         WRITE(*,'(A\)') '     Enter Tank OR Rate: '
         READ(*,*) TANK(3)
         WRITE(*,'(A\)') '     Enter Initial  HEMTTS: '
         READ(*,*) RHEMTT(1)
         WRITE(*,'(A\)') '     Enter HEMTT Fuel Capacity: '
         READ(*,*) RHEMTT(2)
         WRITE(*,'(A\)') '     Enter HEMTT OR Rate: '
         READ(*,*) RHEMTT(3)
         WRITE(*,'(A\)') '     Enter HEMTT Human Factor: '
         READ(*,*) RHEMTT(4)
         WRITE(*,'(A\)') '     Enter Tank Fuel Consumption (Gal/Hr): '
         READ(*,*) FCR
         WRITE(*,'(A\)') '     Enter Max  Refuels Per Day: '
         READ(*,*) REFUEL
         WRITE(*,*) ' '
         WRITE(2,*) (TANK(I), I=1, 3)
         WRITE(2,*) (RHEMTT(I), I=1, 4)
         WRITE(2,*) FCR, REFUEL

C****determine if the user wants to alter the attrition coefficients
WRITE(*,*) 'Do You Want to Change the Default Attrition ',

         WRITE(*,'(A\)') ' Coefficients (Y/N): '
         READ(*,'(A1)') ATEST
```

```
C****default attrition coefficients to be used only if user choses
C****to open a new file and default coefficients (option 1) or
C****to use default values for the simulation ( option 3)
C****read into the program on the first run only when required.

      IF (NNRUN .GT. 1) GO TO 15

C****attrition coefficients for the HEMTT

C****DAY 1 - 30
20    AH(1) = .00552
C****DAY 31 - 60
      AH(2) = .00638
C****DAY 61 - 90
      AH(3) = .00518
C****DAY 91 - 120
      AH(4) = .00428
C****DAY 121 - 150
      AH(5) = .00084
C****DAY 151 - 180
      AH(6) = .00070

C****attrition coefficients for the tank (M-1A1)

C****DAY 1 - 30
      AT(1) = .0091
C****DAY 31 - 60
      AT(2) = .0088
C****DAY 61 - 90
      AT(3) = .00152
C****DAY 91 - 120
      AT(4) = .00050
C****DAY 121 - 150
      AT(5) = .00021
C****DAY 151 - 180
      AT(6) = .00018

C****if the user chose option 1
C****then start the simulation at line 15
      IF (NOPT .EQ. 1) GO TO 15
```

```
C****if the user chose option number 3
C****then read in the remaining default values

      TANK(1) = 58
      TANK(2) = 550.
      TANK(3) =  .92
      RHEMTT(1) = 10
      RHEMTT(2) = 2500.
      RHEMTT(3) =  .89
      RHEMTT(4) =  .93
      FCR = 25.23
      REFUEL = 2

C****if the simulation run number is greater than the number of runs
C****specified by the user
C****then stop the simulation

15    CALL BLANK
      IF (NNRUN .GT. NRUN) THEN
         STOP
      END IF
C****print to the screen the run number of the simulation that
C****is currently executing
      WRITE(*,400) NNRUN

C****set the values input equal to the simulation variable name

      XX(1) = TANK(1)
      XX(2) = RHEMTT(1)
      XX(3) = REFUEL
      XX(6) = TANK(2)
      XX(7) = RHEMTT(2)
      XX(8) = FCR
      XX(10) = 0.0
      XX(11) = 0.0
      XX(12) = TANK(3)
      XX(13) = RHEMTT(3)
      XX(14) = RHEMTT(4)

C****calculate the time of first refuel operation
C**** Time = (Fuel Capacity - Safety Factor) / Attrition Rate

      XX(9) = (XX(6) - 50.) / (XX(8) * 24.)
```

```
C****If the number of audit trails printed is less than 5 and
C****run number of the simulation corresponds to run specified by
C****by the user to be printed
C****then print run number header to SIM.OUT file

      IF (NPTR .LE. 5 .AND. NNPRNT(NPTR) .EQ. NNRUN) WRITE(3,100) NNRUN
      RETURN
100   FORMAT (1X,'***** SIMULATION RUN NUMBER ',I3, ' *****',//)
200   FORMAT (1X,'Enter Tank Attrition Coefficient ',I1, ' : ')
300   FORMAT (1X,'Enter HEMTT Attrition Coefficient ',I1, ' : ')
400   FORMAT (1X,'Simulation Executing -- Run  ',I3,' ...')
      END

C****subroutine blank clears the screen and readies it for new input

      SUBROUTINE BLANK
      DO 10 I = 1, 25
         WRITE(*,*) ' '
10    CONTINUE
      RETURN
      END

C****subroutine error prompts user for another response

      SUBROUTINE ERR

      CHARACTER*2 DUMMY
      WRITE(*,*) '***** Invalid Response *****'
      WRITE(*,*) 'Hit Return to Continue'.
      READ(*,'(A1)') DUMMY
      RETURN
      END
```

```
      SUBROUTINE EVENT(I)

C***************************************************************
C This Subroutine has two events which are called as the
C simulation is running. They are as follows:
C          EVENT 1 -  Simulates the refuel of tanks
C          Event 2 -  Simulates the 2400 clock
C
C***************************************************************


      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP, NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/USER1/AH(6), AT(6), TANK(3), RHEMTT(4), FCR, REFUEL, NRUN,
     1            NPTR, NNPRNT(5)

      GO TO(1,2) I


C***************************************************************
C
C   EVENT 1  This event simulates the refuel of the tank fleet.
C            It monitors the number of refuels conducted during the
C            day, if appropriate conducts the refuel, and tabulates
C            data on the refuel operation. It also prints the adult
C            trail for user specified runs. This event also schedules
C            the next refuel point.
C
C***************************************************************


C****determine the correct month so that the appropriate attrition
C****rate will be applied

1     IF (TNOW.GT.150) THEN
          II=6
      ELSE IF (TNOW.GT.120) THEN
          II=5
      ELSE IF (TNOW.GT.90) THEN
          II=4
      ELSE IF (TNOW.GT.60) THEN
          II=3
      ELSE IF (TNOW.GT.30) THEN
          II=2
      ELSE II=1
      END IF
```

```
C****check for the end of battle
C****if tank battalion has survived 180 days set flags for
C****output statements
      If (TNOW .GT. 180) THEN
         ATRIB(1) = -1
         ATRIB(2) = -1
         IF (NPTR .LE. 5 .AND. NNPRNT(NPTR) .EQ. NNRUN) WRITE (3,65)
         GO TO 90

      END IF

C****increment the refuel counter

      XX(10) = XX(10) + 1

C****determine whether refuel is possible
C****if not possible
C****then set output flags for output statements

      IF (XX(10) .GT. XX(3)) THEN
         ATRIB(1) = -1
         IF (NPTR .LE. 5 .AND. NNPRNT(NPTR) .EQ. NNRUN) WRITE (3,70)
         GO TO 90
      END IF
C****if possible
C****conduct refuel operation

C****determine the number of tanks alive
C****Tnknow = Tnklast - a * Tnklast * (Tnow - Tlast)

      XX(4) = XX(1) - AT(II) * XX(1) * (TNOW - XX(11))

C****determine the number of HEMTTs alive
C****HEMTTSnow = HEMTTSlast - b * HEMTTSlast * (Tnow - Tlast)

      XX(5) = XX(2) - AH(II) * XX(2) * (TNOW - XX(11))

C****determine the expected number of operational tanks to be refueled
C****Tanks for Refuel = Tnknow * ORrate

      XX(15) = XX(4) * XX(12)

C****determine the expected number of operational HEMTTS available
C****for refuel operations
C****HEMTTs Available = HEMTTnow * ORrate * Human Factor

      XX(16) = XX(5) * XX(13) * XX(14)
```

```
C****determine the number of tanks that actually get refueled
C****this is the minimum of operational tanks and Binomial
C****Tanks Avl = Min (Tanks Avail, Bern)

      N = NINT(XX(15))
      P = 0.97
      XX(17) = BERN(N,P,3)
      XX(17) = AMIN1 (XX(15), XX(17))

C****determine the number of HEMTTs that actually get refueled
C****this is the minimum of operational HEMTTs and Binomial
C****Number Of HEMTTs To Arrive At The Refuel Point
C****HEMTTs Aval = Min (HEMTT avail, Bern)

      N = NINT(XX(16))
      P = 0.95
      XX(18) = BERN(N,P,5)
      XX(18) = AMIN1 (XX(16), XX(18))

C****calculate the fuel available for resupply to the tanks

C****determine fuel brought forward by the HEMTTs
C****Favl = HEMTTs avl * Hcap

      XX(19) = XX(18) * XX(7)


C****determine fuel capacity of the tanks operational in the battalion
C****Bndmd = Tnknow * fuel tank capacity

      XX(20) = XX(17) * (XX(6) - 50.0)

C****determine the actual amount of fuel resupplied to the battalion
C****Resupply = Min(Favl, Bndmd)

      XX(21) = AMIN1 (XX(19), XX(20))

C****determine the level of fuel supplied to each operational
C****tank in the battalion
C****Fuel = Resupply / Tknow

      XX(22) = XX(21) / XX(15)
```

```
C****reset parameters for the next refuel operation

C****schedule next resupply time
C****Trefuel = (Fuel - Safety Level) / Attrition Rate

      XX(9) = XX(22) / (XX(8) * 24.)

C****reset tnkslast
C****Tnkslast = Tnksnow

      XX(1) = XX(4)

C****reset HEMTTslast
C****HEMTTslast = HEMTTsnow

      XX(2) = XX(5)
C****reset time of last refuel
C****Tlast = Tnow

      XX(11) = TNOW

C****print audit trail data for selected simulation runs

      IF (NPTR .LE. 5 .AND. NNPRNT(NPTR) .EQ. NNRUN) THEN
         WRITE(3,*) 'BN FUEL RQMT = ',XX(20)
         write(3,*) 'FUEL SUPPLIED= ',XX(21)
         write(3,*) 'Time OF NEXT REFUEL = ',XX(9)
         WRITE(3,25) TNOW
         WRITE(3,30) XX(1)
         WRITE(3,35) XX(2)
         WRITE(3,40) XX(22)
         WRITE(3,45) XX(15)
         WRITE(3,50) XX(17)
         WRITE(3,55) XX(16)
         WRITE(3,60) XX(18)
      END IF


25    FORMAT(1X,'REFUEL ON DAY',1X,F6.2)
30    FORMAT(1X,'TANKS',1X,F4.1)
35    FORMAT(1X,'HEMTTS',1X,F4.1)
40    FORMAT(1X,'AVG FUEL LEVEL',1X,F6.1)
45    FORMAT(1X,' TANKS OPERATIONAL = ',F5.2)
50    FORMAT(1X,'    TANKS REFUELED = ',F5.2)
55    FORMAT(1X,' HEMTTS FOR REFUEL = ',F5.2)
60    FORMAT(1X,'  HEMTTS AT REFUEL = ',F5.2,/)
65    FORMAT(/,1X,'**180 DAYS OF CONTINUOUS COMBAT**',//)
70    FORMAT(1X,'BREAK IN CONTINUOUS OPERATIONS',//)
90    RETURN
```

```
C*****************************************************************
C
C   EVENT 2   This event simulates the 2400 hour clock. It resets
C             the daily refuel counter.
C*****************************************************************

2     XX(10) = 0
      RETURN
      END

C****this function is called to determine the number of vehicles that
C****show up at the refuel point. It is used for both the tanks and
C****HEMTTs. The process is a binomial which is just the sum of
C****Bernoulli trials

       REAL FUNCTION BERN(N,P,STRM)
       INTEGER I,STRM
       REAL DRAW, SUM
       SUM = 0.0
       DO 10 I = 1, N
          DRAW = DRAND(STRM)
          IF (DRAW .LE. P) THEN
             SUM = SUM + 1
          END IF
 10    CONTINUE
       BERN = SUM
       RETURN
       END
```

```
      SUBROUTINE OTPUT
C*****************************************************************
C
C     This subroutine prints values at the termination of each
C     simulation. It also incraments the pointer in the output
C     array
C
C*****************************************************************

      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP, NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/USER1/AH(6), AT(6), TANK(3), RHEMTT(4), FCR, REFUEL, NRUN,
     1             NPTR, NNPRNT(5)

C****increment the pointer in the output array NNPRNT

      IF (NPTR .LE. 5 .AND. NNPRNT(NPTR) .EQ. NNRUN) NPTR = NPTR + 1

C****if simulation has run 180 days
C****then print success banner

      IF (ATRIB(2) .EQ. -1) THEN
         WRITE(4,*)'180 DAYS OF CONTINUOUS OPERATIONS '
         GO TO 99
      END IF

C****if simulation has not completed 180 days
C****then print output data strip

C****write termination time in the PLT.OUT file
      WRITE(6,55) TNOW

C****write output data strip to the SIM.OUT file

      WRITE(4,*)' '
      WRITE(4,50) TNOW, XX(22), XX(1), XX(2)
      WRITE(4,*)' '
50    FORMAT(1X,F6.2,3X,F6.1,3X,F8.2,3X,F8.2)
55    FORMAT(F6.2)
99    RETURN

      END
```

User's Guide

Appendix C : User's Guide

Getting Started

The fuel resupply model was designed using FORTRAN subroutines in combination with SLAM II network input statements. Before the simulation can be run, the network portion (FUEL.DAT) and the FORTRAN subroutines (FUEL.FOR) must be prepared for execution.

SLAM II Network. The SLAM input program (FUEL.DAT) must first be translated into an image that can be simulated. Chapter 2 in the SLAM II PC Version User's Manual outlines the procedure to translate the network file. Unless the number of simulation replications desired exceeds 250, there is no need to translate the model. FUEL.TRA on the user's disk is the translated version of the network model and is ready for simulation.

FORTRAN Routines. Before the simulation can be run, the FORTRAN routines in FUEL.FOR must be compiled and linked to the SLAM object library. Chapter 3 in the SLAM II PC Version User's Manual provides instructions to the compile and link the programs. For the user's convenience, the user's disk contains batch files for use in compiling and linking the FORTRAN program (FUEL.FOR).
The command COMP FUEL is all that is required to compile the source file FUEL while LNK FUEL will link the new object

file (FUEL.OBJ) with the SLAM32.LIB and create the executable file FUEL.EXE. The user is reminded that the SLAM32.LIB file on the FORTRAN 3.2 disk is required to link the object file and create an executable file.

Running The Simulation

Once the executable and the translated files have been created, the simulation can be run. With either SLAM II master disk (INPUT.EXE or OUTPUT.EXE)in the A: drive, the simulation can be started by simply entering from the key board the name of the executable file. In this instance, the name FUEL followed by a return would start the simulation. The program will prompt the user for the name of the translated file and typing FUEL.TRA followed by a return as input will allow the simulation to continue.

Before being prompted for responses, the program reminds the user that the maximum number of simulations is set at 250 and that no more than 5 simulation replications may be specified as audit trails. The user is also reminded that attrition coefficients are specified for each 30 days of battle and that output files should be renamed after the simulation is completed. When the user responds with a

return, the simulation will begin to prompt the user for initial input.

First, the user must specify the number of replications the simulation should make. Then, the number of audit trails to be collected must be specified. The user is then prompted to specify the run numbers of the audit trails. These numbers must be entered one at a time, separated by a space, and in ascending order. After the final number is selected a return by the user will prompt the simulation to continue. It is important that the total number of audit trails specified not exceed the number of replications previously input by the user. Likewise, it is important that a run number not be greater in magnitude than the total number of replications to be simulated.

Input Data

Next, the user wil be required to specify the data that will be used to run the simulation. The user is presented with several choices. Either a new data file can be built, an existing one can be used, default values in the simulation can be used, or the user can exit the simulation.

New Configuration File. If the user chooses to build a new configuration file, the program will prompt the user for a filename in which to store the new data and then proceed

to prompt the user for input values. Data will be prompted in the following sequence:

1) Initial number of tanks
2) Tank's fuel tank capacity
3) Tank's OR rate
4) Initial number of HEMTTs
5) HEMTT fuel haul capacity
6) HEMTT's OR rate
7) Human factor rate for HEMTTs
8) Tank's fuel consumption rate (gal/hr)
9) Maximum number of refuels allowed per day

The user then has the opportunity to use default attrition coefficients or to specify new ones. The coefficients are for thirty day periods beginning on the first day of the battle and concluding on day 180. Should the user decide against using the default values, the simulation will prompt the user first for the tank's coefficients for each of the six periods and then for the HEMTT's coefficients.

Existing Configuration File. When the user specifies that data will be provided by using an existing data file, the simulation prompts the user for a filename. The name must be specified utilizing standard format; up to eight characters for the name and three for the extension.

Default. If this option is selected by the user, further input is not required for the simulation to begin executing. The default values are:

Initial number of tanks	:58
Tank's fuel tank capacity	:550
Tank's OR rate	:.92
Initial number of HEMTTs	:10
HEMTT fuel haul capacity	:2500
HEMTT's OR rate	:.89
Human factor rate for HEMTTs	:.93
Tank's fuel consumption rate (gal/hr)	:25.23
Maximum number of refuels allowed per day	:2

In addition to the above parameters, the default attrition coefficients for the tank and HEMTT will be used. They are as follows:

PERIOD(days)	TANK	HEMTT
1 - 30	.0091	.00552
31 - 60	.0088	.00638
61 - 90	.00152	.00518
91 - 120	.00050	.00428
121 - 150	.00021	.00084
151 - 180	.00018	.00070

Exit. This final option allows the user to leave the program before it starts executing. After this point, the user can stop the program only by executing a CONTROL-C key stroke. Such an action may cause data from the simulation to be lost prior to being printed in the output files.

Altering The Program

The number of replications to be executed and the number of audit trails to be recorded can both be increased. However; before either modification is made it is recommended that the user run the program and develp an awareness of the time required to run the program and the file space required for the output.

Replications. The number of runs can easily be raised from 250 to a much larger number. The user must first alter the FUEL.DAT program by changing the first line of the SLAM code. The fifth field of the GEN statement, specifies the number of replications to be executed. The number 250 currently there must be changed to the desired number of replications. After editing the GEN statement, an appropriate number of SEED and SIMULATE statements should be added to the end of the program. This addition allows the the exact replication of a simulation in the future.

After the above changes have been made, the FUEL.DAT program must be translated before the simulation can be executed. Again the user is referred to chapter 2 in the SLAM II PC Version User's Manual.

Audit Trails. Currently, the program is designed to provide the user up to five audit trails. This, like the number of replications, can be increased by the user. The user must first redimensionalize the array NNPRNT(5) to the

required size. Thi~ array is part of the 'COMMON/USER1//' block and is specified in the main program and at the beginning of each subroutine. The second change that must be made is between lines 5 and 6 in the INTLC subroutine. The statement 'DO 5 I=1,5' must be altered. The number 5 should be replaced with the number that was used to redimensionalize the array NNPRNT( ).

The above changes to the FORTRAN routines will not preclude the user from having to enter the run numbers in ascending order. The changes will necessitate that the user compile and link the new program to create a new executable file prior to being able to execute the simulation.

Output

The simulation opens three files to store output data in: AGG.OUT, PLT.OUT, and SIM.OUT. Each of these files has its own special purpose and the user is reminded to change the names of the files after the simulation has been completed so as to preclude overwriting the data with new data during the next simulation.

AGG.OUT. The AGG.OUT gives the user a summary of terminal data from each replication of the simulation. If the battalion conducts continuous operations for 180 days, then the file contains an entry for the replication that marks the success. In the case of a failure to meet the

standard, the time of failure, last average refuel level, and numbers of surviving tanks and HEMTTs are printed to the file.

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
104.99	328.4	41.37	6.63
28.88	285.1	57.18	8.85
109.79	195.8	41.64	5.72
113.94	262.5	41.41	5.62

Sample AGG.OUT File

PLT.OUT. The PLT.OUT file provides the user with a record of the time of failure for each replication of the simulation that terminates prior to the 180 day point. This file has only numerical characters and is ready for analysis with the aid of a statistical package.

104.99
28.88
109.79
113.94

Sample PLT.OUT File

SIM.OUT. The final file opened by the simulation is called SIM.OUT. It is in this file that the user will

locate the audit trails specified at the start of the simulation.

```
***** SIMULATION RUN NUMBER  27 *****

  BN FUEL RQMT =       24500.0000000
  FUEL SUPPLIED=       20000.0000000
  TIME OF NEXT REFUEL =   6.236794E-001
  REFUEL ON DAY    .83
  TANKS 57.6
  HEMMTS  10.0
  AVG FUEL LEVEL  377.7
  # TANKS OPERATIONAL = 52.96
  #    TANKS REFUELED = 49.00
  # HEMMTS FOR REFUEL =  8.24
  #   HEMTTS AT REFUEL =  8.00

  BN FUEL RQMT =       25500.0000000
  FUEL SUPPLIED=       15000.0000000
  TIME OF NEXT REFUEL =   4.704295E-001
  REFUEL ON DAY   1.45
  TANKS 57.2
  HEMTTS  9.9
  AVG FUEL LEVEL  284.9
  # TANKS OPERATIONAL = 52.66
  #    TANKS REFUELED = 51.00
  # HEMTTS FOR REFUEL =  8.21
  #   HEMTTS AT REFUEL =  6.00
```

BREAK IN CONTINUOUS OPERATIONS
Sample SIM.OUT File

Sample SIM.OUT File

Appendix D : Sample SIM.OUT File

```
***** SIMULATION RUN NUMBER  34 *****


 BN FUEL RQMT =       26500.0000000
 FUEL SUPPLIED=       17500.0000000
 TIME OF NEXT REFUEL =   5.417128E-001
 REFUEL ON DAY    .83
 TANKS 58.0
 HEMTTS  9.9
 AVG FUEL LEVEL  328.0
# TANKS OPERATIONAL = 53.35
#    TANKS REFUELED = 53.00
# HEMTTS FOR REFUEL =  8.22
#  HEMTTS AT REFUEL =  7.00


 BN FUEL RQMT =       26000.0000000
 FUEL SUPPLIED=       17500.0000000
 TIME OF NEXT REFUEL =   5.417744E-001
 REFUEL ON DAY   1.37
 TANKS 58.0
 HEMTTS  9.9
 AVG FUEL LEVEL  328.1
# TANKS OPERATIONAL = 53.34
#    TANKS REFUELED = 52.00
# HEMTTS FOR REFUEL =  8.18
#  HEMTTS AT REFUEL =  7.00


 BN FUEL RQMT =       26000.0000000
 FUEL SUPPLIED=       20000.0000000
 TIME OF NEXT REFUEL =   6.192411E-001
 REFUEL ON DAY   1.91
 TANKS 58.0
 HEMTTS  9.8
 AVG FUEL LEVEL  375.0
# TANKS OPERATIONAL = 53.34
#    TANKS REFUELED = 52.00
# HEMTTS FOR REFUEL =  8.14
#  HEMTTS AT REFUEL =  8.00
```

Appendix D : Sample SIM.OUT File

```
 BN FUEL RQMT =       26500.0000000
 FUEL SUPPLIED=       20000.0000000
 TIME OF NEXT REFUEL =   6.193217E-001
 REFUEL ON DAY   2.53
 TANKS 58.0
 HEMTTS  9.8
 AVG FUEL LEVEL  375.0
# TANKS OPERATIONAL = 53.33
#    TANKS REFUELED = 53.00
# HEMTTS FOR REFUEL =  8.10
#  HEMTTS AT REFUEL =  8.00

 BN FUEL RQMT =       25000.0000000
 FUEL SUPPLIED=       20000.0000000
 TIME OF NEXT REFUEL =   6.194022E-001
 REFUEL ON DAY   3.15
 TANKS 58.0
 HEMTTS  9.7
 AVG FUEL LEVEL  375.1
# TANKS OPERATIONAL = 53.32
#    TANKS REFUELED = 50.00
# HEMTTS FOR REFUEL =  8.06
#  HEMTTS AT REFUEL =  8.00

 BN FUEL RQMT =       26000.0000000
 FUEL SUPPLIED=       20000.0000000
 TIME OF NEXT REFUEL =   6.194828E-001
 REFUEL ON DAY   3.77
 TANKS 58.0
 HEMTTS  9.7
 AVG FUEL LEVEL  375.1
# TANKS OPERATIONAL = 53.32
#    TANKS REFUELED = 52.00
# HEMTTS FOR REFUEL =  8.02
#  HEMTTS AT REFUEL =  8.00
```

```
 BN FUEL RQMT =        26000.0000000
 FUEL SUPPLIED=        17500.0000000
 TIME OF NEXT REFUEL =    5.421180E-001
 REFUEL ON DAY   4.39
 TANKS 57.9
 HEMTTS  9.6
 AVG FUEL LEVEL  328.3
# TANKS OPERATIONAL = 53.31
#    TANKS REFUELED = 52.00
# HEMTTS FOR REFUEL =  7.98
#  HEMTTS AT REFUEL =  7.00

 BN FUEL RQMT =        25000.0000000
 FUEL SUPPLIED=        19851.1100000
 TIME OF NEXT REFUEL =    6.150210E-001
 REFUEL ON DAY   4.93
 TANKS 57.9
 HEMTTS  9.6
 AVG FUEL LEVEL  372.4
# TANKS OPERATIONAL = 53.30
#    TANKS REFUELED = 50.00
# HEMTTS FOR REFUEL =  7.94
#  HEMTTS AT REFUEL =  7.94

 BN FUEL RQMT =        23500.0000000
 FUEL SUPPLIED=        19748.5500000
 TIME OF NEXT REFUEL =    6.119227E-001
 REFUEL ON DAY   5.54
 TANKS 57.9
 HEMTTS  9.5
 AVG FUEL LEVEL  370.5
# TANKS OPERATIONAL = 53.30
#    TANKS REFUELED = 47.00
# HEMTTS FOR REFUEL =  7.90
#  HEMTTS AT REFUEL =  7.90
```

```
 BN FUEL RQMT =        25500.0000000
 FUEL SUPPLIED=        17500.0000000
 TIME OF NEXT REFUEL =    5.423194E-001
 REFUEL ON DAY   6.16
 TANKS 57.9
 HEMTTS  9.5
 AVG FUEL LEVEL  328.4
# TANKS OPERATIONAL = 53.29
#    TANKS REFUELED = 51.00
# HEMTTS FOR REFUEL =  7.86
#  HEMTTS AT REFUEL =  7.00

 BN FUEL RQMT =        25500.0000000
 FUEL SUPPLIED=        17500.0000000
 TIME OF NEXT REFUEL =    5.423812E-001
 REFUEL ON DAY   6.70
 TANKS 57.9
 HEMTTS  9.5
 AVG FUEL LEVEL  328.4
# TANKS OPERATIONAL = 53.28
#    TANKS REFUELED = 51.00
# HEMTTS FOR REFUEL =  7.82
#  HEMTTS AT REFUEL =  7.00

 BN FUEL RQMT =        25500.0000000
 FUEL SUPPLIED=        19468.4400000
 TIME OF NEXT REFUEL =    6.034580E-001
 REFUEL ON DAY   7.24
 TANKS 57.9
 HEMTTS  9.4
 AVG FUEL LEVEL  365.4
# TANKS OPERATIONAL = 53.28
#    TANKS REFUELED = 51.00
# HEMTTS FOR REFUEL =  7.79
#  HEMTTS AT REFUEL =  7.79
```

```
 BN FUEL RQMT =        25000.0000000
 FUEL SUPPLIED=        17500.0000000
 TIME OF NEXT REFUEL =    5.425117E-001
 REFUEL ON DAY    7.84
 TANKS 57.9
 HEMTTS  9.4
 AVG FUEL LEVEL  328.5
# TANKS OPERATIONAL = 53.27
#    TANKS REFUELED = 50.00
# HEMTTS FOR REFUEL =  7.75
#  HEMTTS AT REFUEL =  7.00

 BN FUEL RQMT =        26500.0000000
 FUEL SUPPLIED=        19281.4800000
 TIME OF NEXT REFUEL =    5.978068E-001
 REFUEL ON DAY    8.39
 TANKS 57.9
 HEMTTS  9.3
 AVG FUEL LEVEL  362.0
# TANKS OPERATIONAL = 53.27
#    TANKS REFUELED = 53.00
# HEMTTS FOR REFUEL =  7.71
#  HEMTTS AT REFUEL =  7.71

 BN FUEL RQMT =        25000.0000000
 FUEL SUPPLIED=        19184.6500000
 TIME OF NEXT REFUEL =    5.948795E-001
 REFUEL ON DAY    8.98
 TANKS 57.9
 HEMTTS  9.3
 AVG FUEL LEVEL  360.2
# TANKS OPERATIONAL = 53.26
#    TANKS REFUELED = 50.00
# HEMTTS FOR REFUEL =  7.67
#  HEMTTS AT REFUEL =  7.67
```

```
 BN FUEL RQMT =        25500.0000000
 FUEL SUPPLIED=        19088.7900000
 TIME OF NEXT REFUEL =    5.919809E-001
 REFUEL ON DAY   9.58
 TANKS 57.9
 HEMTTS  9.2
 AVG FUEL LEVEL  358.5
# TANKS OPERATIONAL = 53.25
#    TANKS REFUELED = 51.00
# HEMTTS FOR REFUEL =  7.64
#  HEMTTS AT REFUEL =  7.64

 BN FUEL RQMT =        26500.0000000
 FUEL SUPPLIED=        18993.8700000
 TIME OF NEXT REFUEL =    5.891104E-001
 REFUEL ON DAY  10.17
 TANKS 57.9
 HEMTTS  9.2
 AVG FUEL LEVEL  356.7
# TANKS OPERATIONAL = 53.25
#    TANKS REFUELED = 53.00
# HEMTTS FOR REFUEL =  7.60
#  HEMTTS AT REFUEL =  7.60

 BN FUEL RQMT =        26500.0000000
 FUEL SUPPLIED=        18899.8700000
 TIME OF NEXT REFUEL =    5.862677E-001
 REFUEL ON DAY  10.76
 TANKS 57.9
 HEMTTS  9.1
 AVG FUEL LEVEL  355.0
# TANKS OPERATIONAL = 53.24
#    TANKS REFUELED = 53.00
# HEMTTS FOR REFUEL =  7.56
#  HEMTTS AT REFUEL =  7.56
```

```
 BN FUEL RQMT =        26000.0000000
 FUEL SUPPLIED=        18806.8000000
 TIME OF NEXT REFUEL =    5.834523E-001
 REFUEL ON DAY  11.35
 TANKS 57.9
 HEMTTS  9.1
 AVG FUEL LEVEL  353.3
# TANKS OPERATIONAL = 53.23
#    TANKS REFUELED = 52.00
# HEMTTS FOR REFUEL =  7.52
#  HEMTTS AT REFUEL =  7.52

 BN FUEL RQMT =        25000.0000000
 FUEL SUPPLIED=        17500.0000000
 TIME OF NEXT REFUEL =    5.429774E-001
 REFUEL ON DAY  11.93
 TANKS 57.9
 HEMTTS  9.0
 AVG FUEL LEVEL  328.8
# TANKS OPERATIONAL = 53.23
#    TANKS REFUELED = 50.00
# HEMTTS FOR REFUEL =  7.49
#  HEMTTS AT REFUEL =  7.00

 BN FUEL RQMT =        26500.0000000
 FUEL SUPPLIED=        17500.0000000
 TIME OF NEXT REFUEL =    5.430393E-001
 REFUEL ON DAY  12.47
 TANKS 57.8
 HEMTTS  9.0
 AVG FUEL LEVEL  328.8
# TANKS OPERATIONAL = 53.22
#    TANKS REFUELED = 53.00
# HEMTTS FOR REFUEL =  7.45
#  HEMTTS AT REFUEL =  7.00
```

```
 BN FUEL RQMT =        26000.0000000
 FUEL SUPPLIED=        17500.0000000
 TIME OF NEXT REFUEL =    5.431012E-001
 REFUEL ON DAY  13.02
 TANKS 57.8
 HEMTTS  9.0
 AVG FUEL LEVEL  328.9
# TANKS OPERATIONAL = 53.21
#    TANKS REFUELED = 52.00
# HEMTTS FOR REFUEL =  7.42
#  HEMTTS AT REFUEL =  7.00

 BN FUEL RQMT =        26500.0000000
 FUEL SUPPLIED=        17500.0000000
 TIME OF NEXT REFUEL =    5.431632E-001
 REFUEL ON DAY  13.56
 TANKS 57.8
 HEMTTS  8.9
 AVG FUEL LEVEL  328.9
# TANKS OPERATIONAL = 53.21
#    TANKS REFUELED = 53.00
# HEMTTS FOR REFUEL =  7.38
#  HEMTTS AT REFUEL =  7.00

 BN FUEL RQMT =        24500.0000000
 FUEL SUPPLIED=        17500.0000000
 TIME OF NEXT REFUEL =    5.432251E-001
 REFUEL ON DAY  14.10
 TANKS 57.8
 HEMTTS  8.9
 AVG FUEL LEVEL  328.9
# TANKS OPERATIONAL = 53.20
#    TANKS REFUELED = 49.00
# HEMTTS FOR REFUEL =  7.35
#  HEMTTS AT REFUEL =  7.00
```

```
 BN FUEL RQMT =       26000.0000000
 FUEL SUPPLIED=       17500.0000000
 TIME OF NEXT REFUEL =    5.432871E-001
 REFUEL ON DAY  14.65
 TANKS 57.8
 HEMTTS  8.8
 AVG FUEL LEVEL  329.0
# TANKS OPERATIONAL = 53.20
#    TANKS REFUELED = 52.00
# HEMTTS FOR REFUEL =  7.32
#  HEMTTS AT REFUEL =  7.00

 BN FUEL RQMT =       26000.0000000
 FUEL SUPPLIED=       15000.0000000
 TIME OF NEXT REFUEL =    4.657278E-001
 REFUEL ON DAY  15.19
 TANKS 57.8
 HEMTTS  8.8
 AVG FUEL LEVEL  282.0
# TANKS OPERATIONAL = 53.19
#    TANKS REFUELED = 52.00
# HEMTTS FOR REFUEL =  7.28
#  HEMTTS AT REFUEL =  6.00

 BN FUEL RQMT =       26000.0000000
 FUEL SUPPLIED=       15000.0000000
 TIME OF NEXT REFUEL =    4.657733E-001
 REFUEL ON DAY  15.65
 TANKS 57.8
 HEMTTS  8.8
 AVG FUEL LEVEL  282.0
# TANKS OPERATIONAL = 53.18
#    TANKS REFUELED = 52.00
# HEMTTS FOR REFUEL =  7.25
#  HEMTTS AT REFUEL =  6.00
```

```
 BN FUEL RQMT =         25500.0000000
 FUEL SUPPLIED=         17500.0000000
 TIME OF NEXT REFUEL =    5.434553E-001
 REFUEL ON DAY  16.12
 TANKS 57.8
 HEMTTS  8.7
 AVG FUEL LEVEL  329.1
# TANKS OPERATIONAL = 53.18
#    TANKS REFUELED = 51.00
# HEMTTS FOR REFUEL =  7.23
#  HEMTTS AT REFUEL =  7.00

 BN FUEL RQMT =         25500.0000000
 FUEL SUPPLIED=         17500.0000000
 TIME OF NEXT REFUEL =    5.435174E-001
 REFUEL ON DAY  16.66
 TANKS 57.8
 HEMTTS  8.7
 AVG FUEL LEVEL  329.1
# TANKS OPERATIONAL = 53.17
#    TANKS REFUELED = 51.00
# HEMTTS FOR REFUEL =  7.19
#  HEMTTS AT REFUEL =  7.00

 BN FUEL RQMT =         25500.0000000
 FUEL SUPPLIED=         15000.0000000
 TIME OF NEXT REFUEL =    4.659252E-001
 REFUEL ON DAY  17.21
 TANKS 57.8
 HEMTTS  8.7
 AVG FUEL LEVEL  282.1
# TANKS OPERATIONAL = 53.17
#    TANKS REFUELED = 51.00
# HEMTTS FOR REFUEL =  7.16
#  HEMTTS AT REFUEL =  6.00
```

```
 BN FUEL RQMT =        26500.0000000
 FUEL SUPPLIED=        17500.0000000
 TIME OF NEXT REFUEL =    5.436326E-001
 REFUEL ON DAY  17.67
 TANKS 57.8
 HEMTTS  8.6
 AVG FUEL LEVEL  329.2
# TANKS OPERATIONAL = 53.16
#    TANKS REFUELED = 53.00
# HEMTTS FOR REFUEL =  7.13
#  HEMTTS AT REFUEL =  7.00

 BN FUEL RQMT =        26500.0000000
 FUEL SUPPLIED=        15000.0000000
 TIME OF NEXT REFUEL =    4.660240E-001
 REFUEL ON DAY  18.22
 TANKS 57.8
 HEMTTS  8.6
 AVG FUEL LEVEL  282.2
# TANKS OPERATIONAL = 53.16
#    TANKS REFUELED = 53.00
# HEMTTS FOR REFUEL =  7.10
#  HEMTTS AT REFUEL =  6.00

 BN FUEL RQMT =        26000.0000000
 FUEL SUPPLIED=        15000.0000000
 TIME OF NEXT REFUEL =    4.660696E-001
 REFUEL ON DAY  18.68
 TANKS 57.8
 HEMTTS  8.5
 AVG FUEL LEVEL  282.2
# TANKS OPERATIONAL = 53.15
#    TANKS REFUELED = 52.00
# HEMTTS FOR REFUEL =  7.07
#  HEMTTS AT REFUEL =  6.00
```

```
 BN FUEL RQMT =         25500.0000000
 FUEL SUPPLIED=         15000.0000000
 TIME OF NEXT REFUEL =    4.661152E-001
 REFUEL ON DAY  19.15
 TANKS 57.8
 HEMTTS  8.5
 AVG FUEL LEVEL  282.2
# TANKS OPERATIONAL = 53.15
#    TANKS REFUELED = 51.00
# HEMTTS FOR REFUEL =  7.04
#  HEMTTS AT REFUEL =  6.00

 BN FUEL RQMT =         26000.0000000
 FUEL SUPPLIED=         10000.0000000
 TIME OF NEXT REFUEL =    3.107738E-001
 REFUEL ON DAY  19.61
 TANKS 57.8
 HEMTTS  8.5
 AVG FUEL LEVEL  188.2
# TANKS OPERATIONAL = 53.14
#    TANKS REFUELED = 52.00
# HEMTTS FOR REFUEL =  7.02
#  HEMTTS AT REFUEL =  4.00


 BREAK IN CONTINUOUS OPERATIONS
```

Sample AGG.OUT File

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
104.99	328.4	41.37	6.63
28.88	285.1	57.18	8.85
109.79	195.8	41.64	5.72
113.94	262.5	41.41	5.62
119.99	262.6	41.40	5.48
77.95	318.5	42.66	6.63
85.99	266.3	40.81	6.19
89.97	267.4	40.66	6.06
105.96	269.7	40.30	5.66
69.96	251.7	43.19	6.91
108.92	202.5	40.25	5.58
86.97	322.1	42.18	6.33
44.92	278.6	48.76	7.80
141.94	254.2	32.07	4.27
15.95	282.0	57.81	8.78

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
30.99	285.2	57.17	7.75
124.98	336.6	32.30	4.95
29.83	235.7	57.64	7.80
27.90	188.5	57.66	7.93
30.97	285.2	57.17	7.75
134.85	253.2	32.19	4.54
23.99	282.5	57.71	8.20
33.92	292.1	55.82	7.60
143.98	253.5	32.16	4.20
25.00	282.6	57.70	8.13
30.99	285.0	57.21	7.75
124.99	252.8	32.24	4.93
32.95	289.6	56.30	7.65
109.98	336.1	32.34	5.37
88.97	258.4	42.06	6.26

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
21.00	241.7	56.21	8.99
47.99	343.7	47.44	7.65
143.89	254.5	32.04	4.20
19.93	188.2	57.76	8.48
34.94	294.8	55.31	7.55
109.73	250.8	32.50	5.37
92.92	259.3	41.92	6.15
77.86	191.2	42.63	6.62
28.00	293.1	55.62	8.67
76.97	328.0	41.42	6.49
97.90	267.9	40.57	5.86
48.97	280.3	48.47	7.81
116.99	252.0	32.34	5.21
100.99	261.6	41.55	5.93
33.99	294.9	55.29	8.59

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
126.99	253.1	32.21	4.84
30.94	285.2	57.17	7.75
137.88	254.2	32.07	4.43
13.94	281.9	57.84	8.93
23.99	235.4	57.71	8.20
27.95	235.6	57.67	7.93
32.97	290.0	56.22	7.65
144.96	254.1	32.08	4.17
29.95	282.9	57.64	7.80
20.95	282.3	57.75	8.42
30.83	237.5	57.21	7.75
133.99	253.7	32.13	4.57
14.86	188.0	57.82	8.85
29.90	282.9	57.64	7.80
18.99	235.2	57.77	8.55

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
22.83	282.4	57.73	8.28
25.90	235.5	57.69	8.07
32.89	241.5	56.26	7.65
136.95	312.7	32.08	4.46
28.90	235.7	57.65	7.87
33.97	292.1	55.82	7.60
112.92	167.8	32.39	5.30
111.88	197.2	41.34	5.66
43.00	319.4	51.04	8.11
134.96	254.1	32.08	4.54
29.94	282.9	57.64	7.80
30.00	235.7	57.64	7.79
32.90	241.5	56.26	7.65
143.99	254.0	32.09	4.21
33.95	243.7	55.74	7.60

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
141.00	301.7	32.18	4.32
30.94	237.7	57.17	7.75
122.98	336.6	32.29	5.03
26.94	235.6	57.68	8.00
14.96	282.0	57.82	8.85
21.99	235.3	57.74	8.34
30.92	284.8	57.24	7.75
143.97	253.5	32.16	4.21
31.90	239.7	56.69	7.70
141.93	300.1	32.09	4.28
27.00	312.0	57.68	8.00
30.94	285.0	57.21	7.75
111.77	251.5	32.42	5.33
81.99	320.1	42.45	6.49
28.97	244.7	55.53	8.62

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
85.95	199.2	40.92	6.19
117.79	270.6	40.17	5.38
93.85	259.4	41.90	6.12
30.96	287.9	56.64	8.76
137.99	254.3	32.06	4.41
14.93	188.0	57.82	8.84
25.93	314.8	57.69	8.07
29.94	282.9	57.64	7.80
29.95	282.9	57.64	7.80
31.93	287.2	56.77	7.70
124.96	252.4	32.29	4.93
32.97	289.4	56.33	7.65
143.92	254.1	32.08	4.20
15.98	282.0	57.81	8.78
20.87	328.2	57.75	8.43

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
21.94	282.4	57.74	8.35
29.81	282.8	57.64	7.81
29.93	235.7	57.64	7.80
30.97	285.0	57.21	7.75
135.00	253.1	32.21	4.53
30.87	237.5	57.21	7.75
144.93	254.6	32.02	4.17
9.88	234.7	57.88	9.23
31.91	239.7	56.69	7.70
120.87	252.6	32.27	5.10
31.87	191.7	56.69	7.70
126.00	252.8	32.25	4.89
28.99	306.9	57.65	7.87
21.96	325.2	57.74	8.35
30.85	237.5	57.21	7.75

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
119.94	253.4	32.17	5.14
75.00	352.0	43.07	6.74
24.95	291.8	55.88	8.81
116.84	203.1	40.14	5.40
83.96	321.9	42.21	6.42
75.89	196.0	41.58	6.52
78.99	328.8	41.32	6.42
86.97	199.4	40.88	6.15
91.99	332.2	40.71	6.01
114.98	262.7	41.37	5.59
86.96	322.8	42.10	6.33
104.92	269.2	40.38	5.69
24.98	284.6	57.29	9.00
86.89	258.0	42.14	6.33
102.89	202.1	40.33	5.73

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
92.78	260.3	41.76	6.15
50.95	228.6	47.56	7.71
133.97	253.9	32.10	4.58
31.82	287.2	56.77	7.71
133.98	320.4	32.13	4.58
21.90	235.3	57.74	8.34
26.87	235.6	57.68	8.00
14.95	282.0	57.82	8.85
32.00	287.4	56.73	7.70
110.97	335.6	32.39	5.35
82.96	321.1	42.31	6.46
116.87	271.9	39.98	5.40
82.89	256.4	42.39	6.46
112.97	270.6	40.17	5.49
89.97	323.9	41.95	6.23

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
117.91	271.5	40.04	5.38
78.95	255.5	42.54	6.59
47.00	284.7	47.73	7.70
115.99	251.8	32.38	5.23
79.90	255.3	42.57	6.56
82.93	330.4	41.12	6.29
52.98	239.4	45.40	7.41
111.00	335.9	32.36	5.34
82.98	256.7	42.34	6.46
94.00	200.5	40.66	5.96
79.93	256.2	42.42	6.55
79.00	263.2	41.30	6.42
82.99	264.9	41.03	6.28
115.98	270.4	40.20	5.42
114.97	197.0	41.38	5.59

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
81.97	320.6	42.38	6.49
72.78	130.3	41.72	6.62
74.92	261.3	41.60	6.55
104.98	317.1	40.32	5.68
94.00	259.3	41.91	6.12
117.98	263.5	41.25	5.52
106.96	196.1	41.57	5.79
79.97	318.1	42.71	6.57
115.97	270.6	40.17	5.42
78.97	254.5	42.71	6.60
117.97	271.3	40.07	5.38
90.98	258.9	41.98	6.20
96.96	260.8	41.67	6.04
29.97	237.7	57.15	8.81
85.96	322.2	42.18	6.36

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
19.97	289.6	56.31	9.04
18.98	241.0	56.38	9.08
20.97	193.4	56.21	8.98
110.99	310.5	40.12	5.54
101.91	320.0	41.59	5.92
27.97	332.5	57.21	8.89
87.89	193.4	42.16	6.29
27.99	293.1	55.62	8.67
19.96	241.3	56.30	9.03
27.89	293.1	55.63	8.67
107.96	270.1	40.25	5.61
34.88	198.4	54.77	8.54
126.86	253.4	32.17	4.86
12.94	234.9	57.85	9.00
4.00	328.2	57.96	9.71

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
15.87	235.0	57.81	8.78
32.84	241.3	56.30	7.65
143.00	297.0	32.17	4.25
35.94	247.8	54.83	7.50
120.99	252.5	32.29	5.10
32.89	241.4	56.30	7.65
114.84	251.4	32.43	5.26
30.96	240.1	56.60	8.75
121.98	253.2	32.20	5.06
30.89	237.5	57.21	7.75
144.87	254.4	32.05	4.17
24.75	188.4	57.70	8.14
23.99	235.4	57.71	8.20
19.95	282.3	57.76	8.49
29.91	188.6	57.64	7.79

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
13.94	281.9	57.84	8.93
32.97	290.0	56.22	7.65
110.86	336.1	32.34	5.35
28.97	237.6	57.18	8.85
80.94	191.5	42.58	6.52
115.94	271.3	40.07	5.42
79.91	191.2	42.63	6.56
92.89	332.2	40.53	5.99
116.98	262.7	41.38	5.55
110.93	196.6	41.46	5.69
54.00	293.3	46.33	7.56
144.90	254.1	32.08	4.17
62.98	246.1	44.17	6.33
92.98	267.4	40.65	5.98
106.97	196.3	41.52	5.78

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
108.99	262.2	41.46	5.74
77.94	254.9	42.65	6.63
25.97	340.9	55.80	8.77
91.00	267.2	40.67	6.04
114.96	262.9	41.35	5.59
81.99	256.3	42.42	6.49
75.90	261.8	41.52	6.52
77.99	262.5	41.41	6.45
105.97	270.3	40.21	5.66
24.93	284.6	57.29	9.00
79.98	318.9	42.60	6.56
36.95	260.2	52.22	8.21
112.98	252.3	32.31	5.30
61.93	248.6	43.73	7.20
76.98	196.6	41.46	6.48

Appendix E : Sample AGG.OUT File

TERMINAL DATA FROM SIMULATION

DAY	REFUEL	TANKS	HEMTTS
94.99	329.1	40.56	5.94
79.96	320.0	42.46	6.56
49.99	291.3	46.65	7.56
129.98	253.8	32.12	4.73
21.96	282.4	57.74	8.34
27.92	282.7	57.67	7.94
30.91	237.7	57.17	7.75
134.90	253.4	32.18	4.54
23.98	282.5	57.71	8.20
32.98	241.5	56.26	7.64

Fuel Inventory

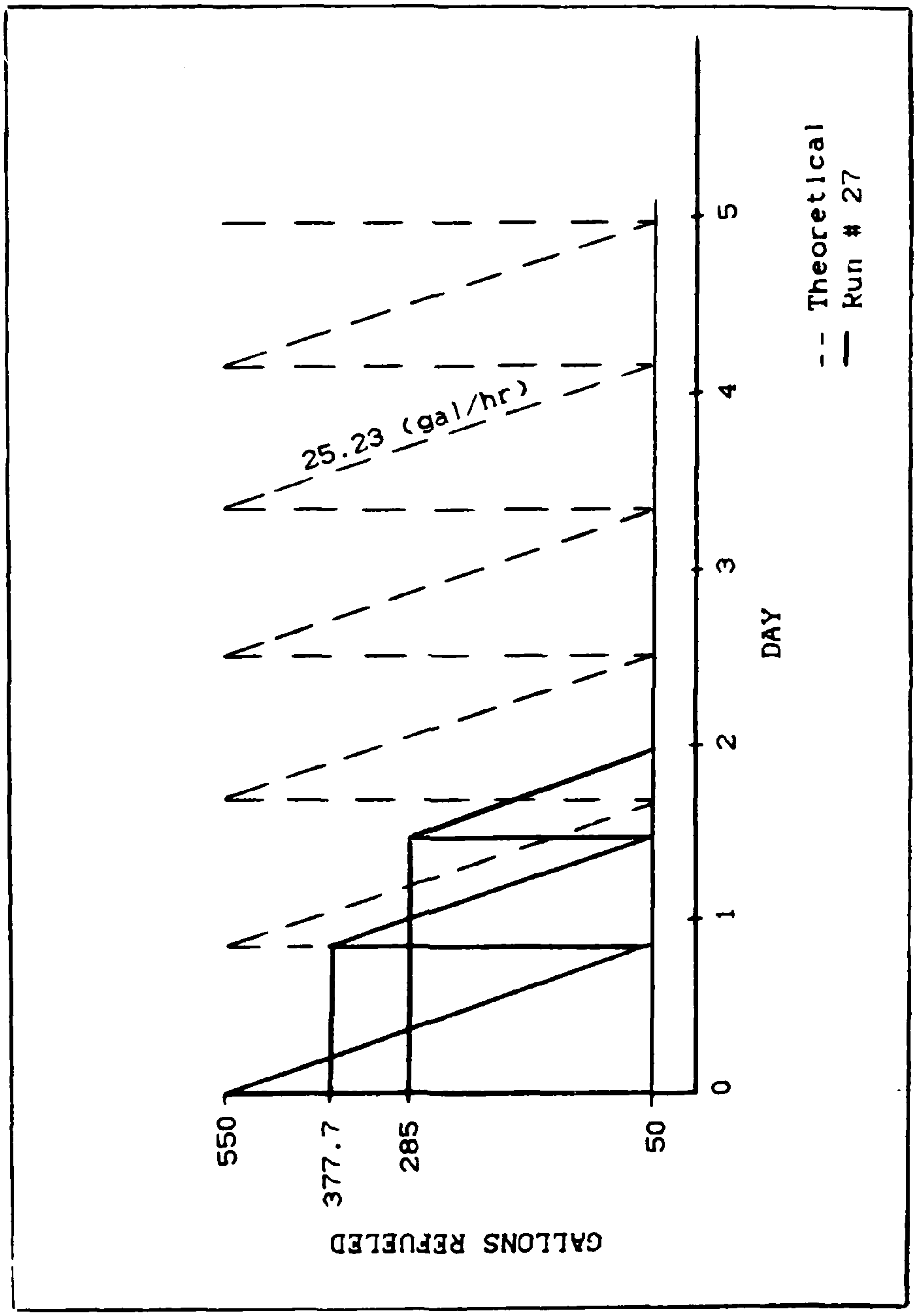

Figure 7. Fuel Inventory - One Refuel Per Day

***** SIMULATION RUN NUMBER 27 *****

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BN FUEL RQMT =       24500.0000000
FUEL SUPPLIED=       20000.0000000
TIME OF NEXT REFUEL =    6.236794E-001
REFUEL ON DAY    .83
TANKS 57.6
HEMMTS  10.0
AVG FUEL LEVEL  377.7
# TANKS OPERATIONAL = 52.96
#    TANKS REFUELED = 49.00
# HEMMTS FOR REFUEL =  8.24
#  HEMTTS AT REFUEL =  8.00

BN FUEL RQMT =       25500.0000000
FUEL SUPPLIED=       15000.0000000
TIME OF NEXT REFUEL =    4.704295E-001
REFUEL ON DAY   1.45
TANKS 57.2
HEMTTS  9.9
AVG FUEL LEVEL  284.9
# TANKS OPERATIONAL = 52.66
#    TANKS REFUELED = 51.00
# HEMTTS FOR REFUEL =  8.21
#  HEMTTS AT REFUEL =  6.00
```

BREAK IN CONTINUOUS OPERATIONS

Default Data

Appendix G : Default Data

TABLE I

Initial Values

Initial number of tanks	:58
Tank's fuel tank capacity	:550
Tank's OR rate	:.92
Initial number of HEMTTs	:10
HEMTT fuel haul capacity	:2500
HEMTT's OR rate	:.89
Human factor rate for HEMTTs	:.93
Tank's fuel consumption rate (gal/hr)	:25.23
Maximum number of refuels allowed per day	:2

TABLE II

Attrition Coefficients

PERIOD (days)	TANK	HEMTT
1 - 30	.0091	.00552
31 - 60	.0088	.00638
61 - 90	.00152	.00518
91 - 120	.00050	.00428
121 - 150	.00021	.00084
151 - 180	.00018	.00070

Histograms

Appendix H : Histograms

TABLE III

Histogram Data - One Refuel Per Day

CLASS	LOWER LIMIT	UPPER LIMIT	MIDPOINT	FREQUENCY	RELATIVE FREQUENCY	CUMULATIVE FREQUENCY	CUM. REL. FREQUENCY
AT OR BELOW		1.70		0	.00000	0	.00000
1	1.70	1.73	1.72	0	.00000	0	.00000
2	1.73	1.77	1.75	1	.00400	1	.00400
3	1.77	1.80	1.78	0	.00000	1	.00400
4	1.80	1.83	1.82	9	.03600	10	.04000
5	1.83	1.87	1.85	0	.00000	10	.04000
6	1.87	1.90	1.88	0	.00000	10	.04000
7	1.90	1.93	1.92	33	.13200	43	.17200
8	1.93	1.97	1.95	0	.00000	43	.17200
9	1.97	2.00	1.98	81	.32400	124	.49600
10	2.00	2.03	2.02	0	.00000	124	.49600
11	2.03	2.07	2.05	0	.00000	124	.49600
12	2.07	2.10	2.08	0	.00000	124	.49600
13	2.10	2.13	2.12	0	.00000	124	.49600
14	2.13	2.17	2.15	0	.00000	124	.49600
15	2.17	2.20	2.18	0	.00000	124	.49600
16	2.20	2.23	2.22	0	.00000	124	.49600
17	2.23	2.27	2.25	0	.00000	124	.49600
18	2.27	2.30	2.28	0	.00000	124	.49600
19	2.30	2.33	2.32	0	.00000	124	.49600
20	2.33	2.37	2.35	0	.00000	124	.49600
21	2.37	2.40	2.38	0	.00000	124	.49600
22	2.40	2.43	2.42	0	.00000	124	.49600
23	2.43	2.47	2.45	2	.00800	126	.50400
24	2.47	2.50	2.48	0	.00000	126	.50400
25	2.50	2.53	2.52	6	.02400	132	.52800
26	2.53	2.57	2.55	0	.00000	132	.52800
27	2.57	2.60	2.58	0	.00000	132	.52800
28	2.60	2.63	2.62	34	.13600	166	.66400
29	2.63	2.67	2.65	0	.00000	166	.66400
30	2.67	2.70	2.68	84	.33600	250	1.00000
ABOVE	2.70			0	.00000	250	1.00000

MEAN = 2.3055 STANDARD DEVIATION = 0.35196 MEDIAN = 2.45

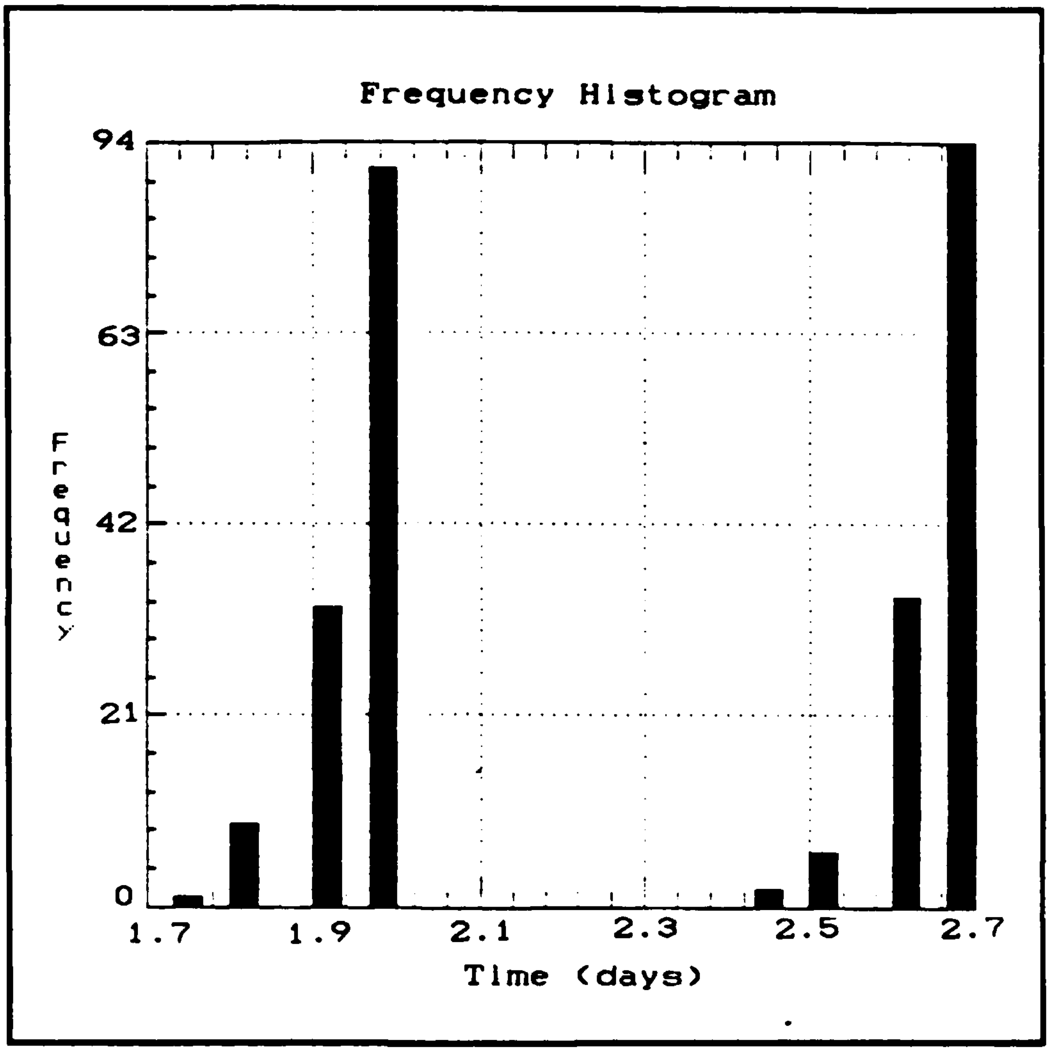

Figure 8. Day of Failure - One Refuel Per Day

Appendix H : Histograms

TABLE IV

Histogram Data - Two Refuels Per Day

CLASS	LOWER LIMIT	UPPER LIMIT	MIDPOINT	FREQUENCY	RELATIVE FREQUENCY	CUMULATIVE FREQUENCY	CUM. REL. FREQUENCY
AT OR BELOW		.00		0	.00000	0	.00000
1	.00	5.00	2.50	1	.00400	1	.00400
2	5.00	10.00	7.50	1	.00400	2	.00800
3	10.00	15.00	12.50	7	.02800	9	.03600
4	15.00	20.00	17.50	9	.03600	18	.07200
5	20.00	25.00	22.50	19	.07600	37	.14800
6	25.00	30.00	27.50	29	.11600	66	.26400
7	30.00	35.00	32.50	36	.14400	102	.40800
8	35.00	40.00	37.50	2	.00800	104	.41600
9	40.00	45.00	42.50	2	.00800	106	.42400
10	45.00	50.00	47.50	4	.01600	110	.44000
11	50.00	55.00	52.50	3	.01200	113	.45200
12	55.00	60.00	57.50	0	.00000	113	.45200
13	60.00	65.00	62.50	2	.00800	115	.46000
14	65.00	70.00	67.50	1	.00400	116	.46400
15	70.00	75.00	72.50	3	.01200	119	.47600
16	75.00	80.00	77.50	18	.07200	137	.54800
17	80.00	85.00	82.50	10	.04000	147	.58800
18	85.00	90.00	87.50	11	.04400	158	.63200
19	90.00	95.00	92.50	11	.04400	169	.67600
20	95.00	100.00	97.50	2	.00800	171	.68400
21	100.00	105.00	102.50	6	.02400	177	.70800
22	105.00	110.00	107.50	10	.04000	187	.74800
23	110.00	115.00	112.50	15	.06000	202	.80800
24	115.00	120.00	117.50	14	.05600	216	.86400
25	120.00	125.00	122.50	7	.02800	223	.89200
26	125.00	130.00	127.50	4	.01600	227	.90800
27	130.00	135.00	132.50	7	.02800	234	.93600
28	135.00	140.00	137.50	3	.01200	237	.94800
29	140.00	145.00	142.50	13	.05200	250	1.00000
30	145.00	150.00	147.50	0	.00000	250	1.00000
ABOVE	150.00			0	.00000	250	1.00000

MEAN = 70.721 STANDARD DEVIATION = 42.212 MEDIAN = 77.945

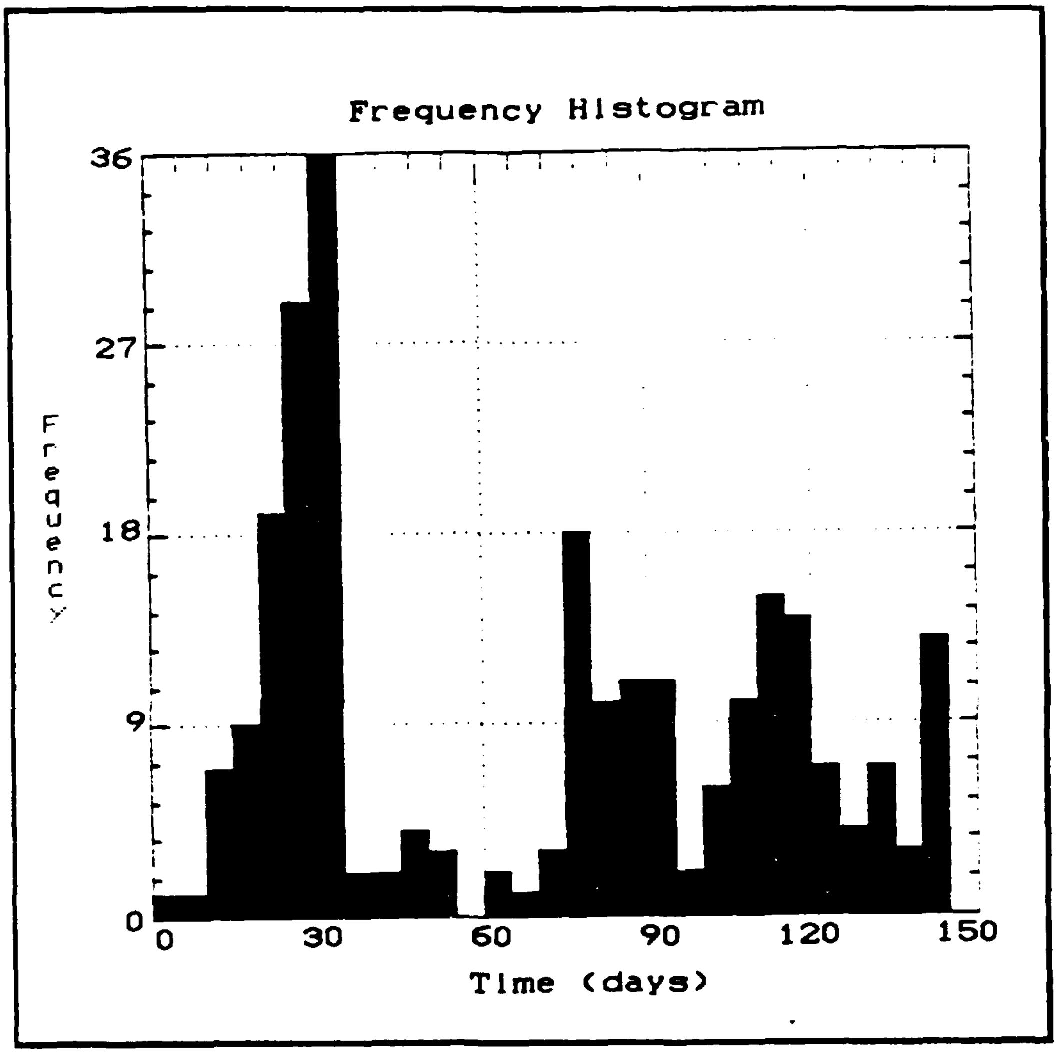

Figure 9. Day of Failure - Two Refuels Per Day

TABLE V

Histogram Data - Three Refuels Per Day

CLASS	LOWER LIMIT	UPPER LIMIT	MIDPOINT	FREQUENCY	RELATIVE FREQUENCY	CUMULATIVE FREQUENCY	CUM. REL. FREQUENCY
AT OR BELOW		93.00		0	.0000	0	.0000
1	93.00	98.56	95.78	1	.0116	1	.0116
2	98.56	104.11	101.33	0	.0000	1	.0116
3	104.11	109.67	106.89	2	.0233	3	.0349
4	109.67	115.22	112.44	0	.0000	3	.0349
5	115.22	120.78	118.00	0	.0000	3	.0349
6	120.78	126.33	123.56	2	.0233	5	.0581
7	126.33	131.89	129.11	1	.0116	6	.0698
8	131.89	137.44	134.67	17	.1977	23	.2674
9	137.44	143.00	140.22	52	.6047	75	.8721
10	143.00	148.56	145.78	1	.0116	76	.8837
11	148.56	154.11	151.33	2	.0233	78	.9070
12	154.11	159.67	156.89	1	.0116	79	.9186
13	159.67	165.22	162.44	4	.0465	83	.9651
14	165.22	170.78	168.00	0	.0000	83	.9651
15	170.78	176.33	173.56	1	.0116	84	.9767
16	176.33	181.89	179.11	2	.0233	86	1.0000
17	181.89	187.44	184.67	0	.0000	86	1.0000
18	187.44	193.00	190.22	0	.0000	86	1.0000
ABOVE	193.00			0	.0000	86	1.0000

MEAN = 139.73 STANDARD DEVIATION = 11.664 MEDIAN = 138.41

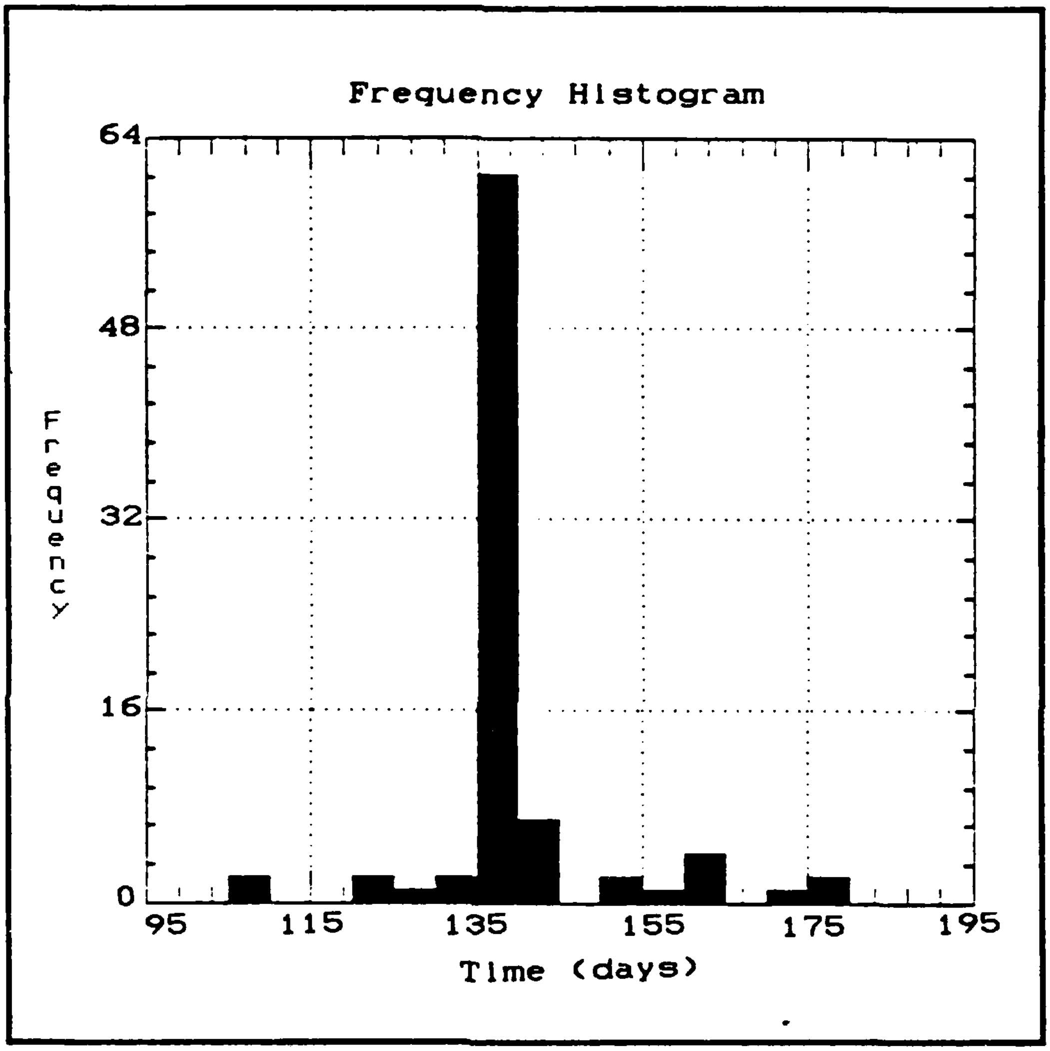

Figure 10. Day of Failure - Three Refuels Per Day

Fuel Consumption

Appendix I : Fuel Consumption

TABLE VI

Fuel Consumption Coefficients

Power Requirement	Rate (gallons/hr)
Idling	11.0
Tactical Idling	17.1
Cross-Country	62.96
Secondary Roads	50.0
Primary Roads	55.96

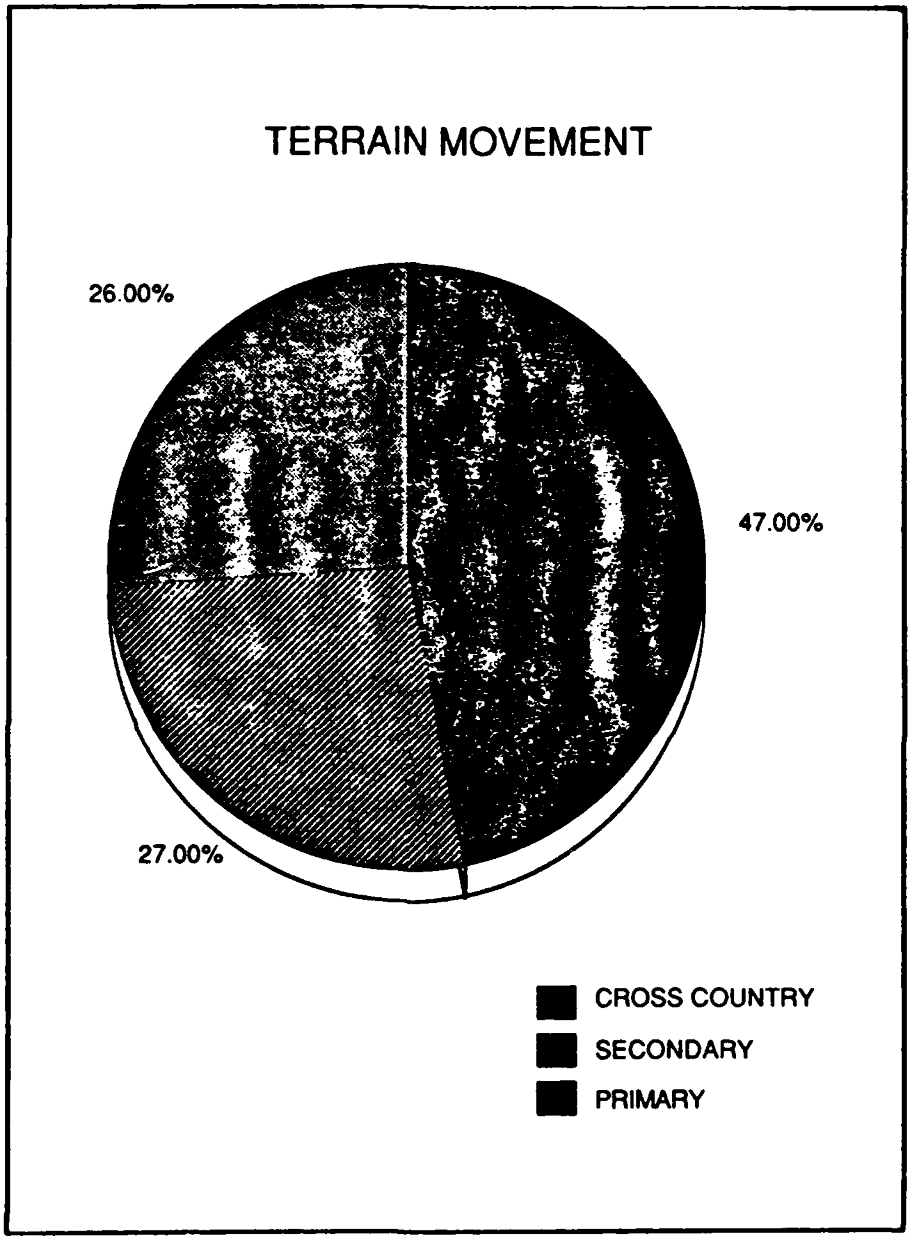

Figure 11. Terrain Movement Profile

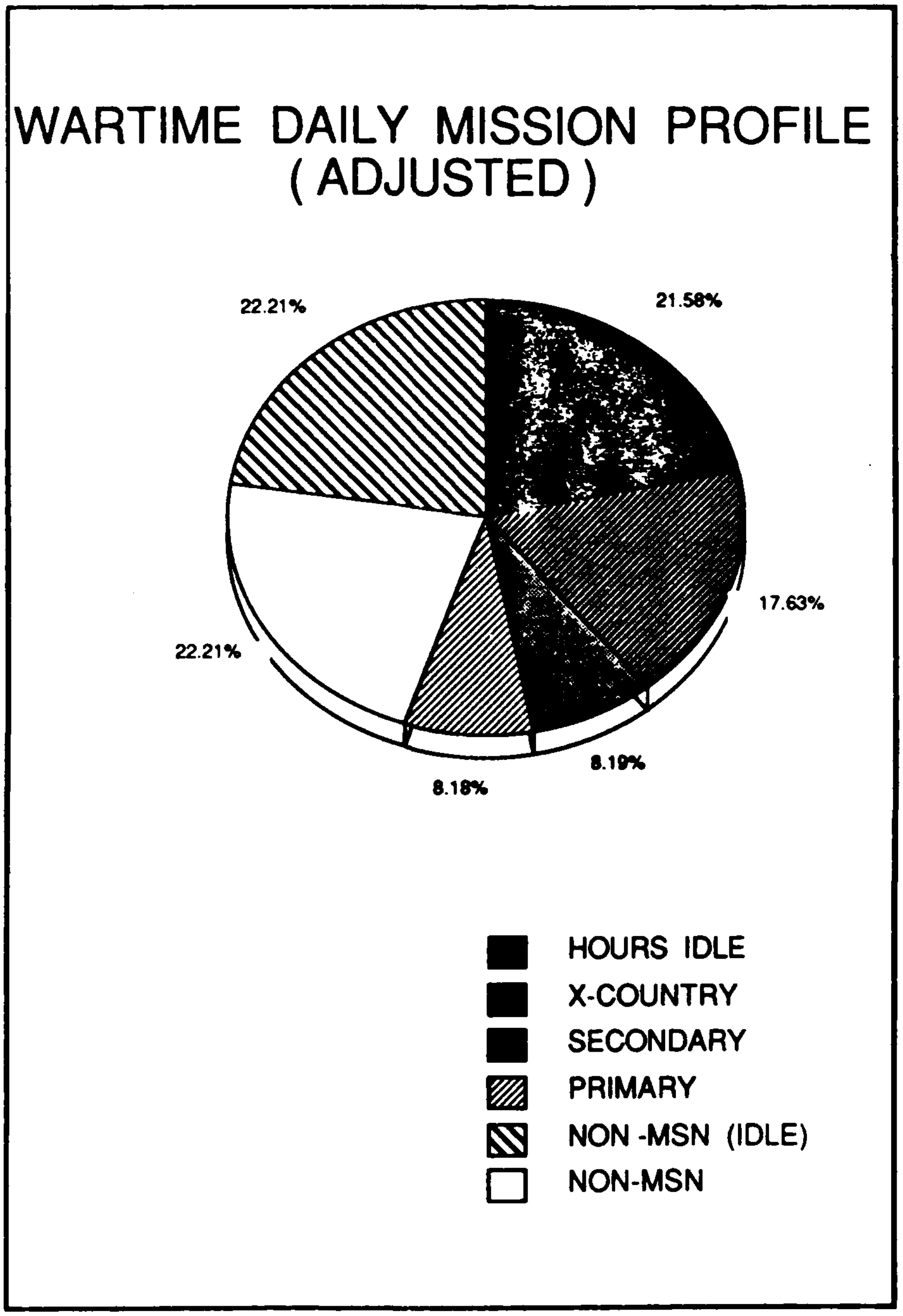

Figure 12. Wartime Daily Mission Profile

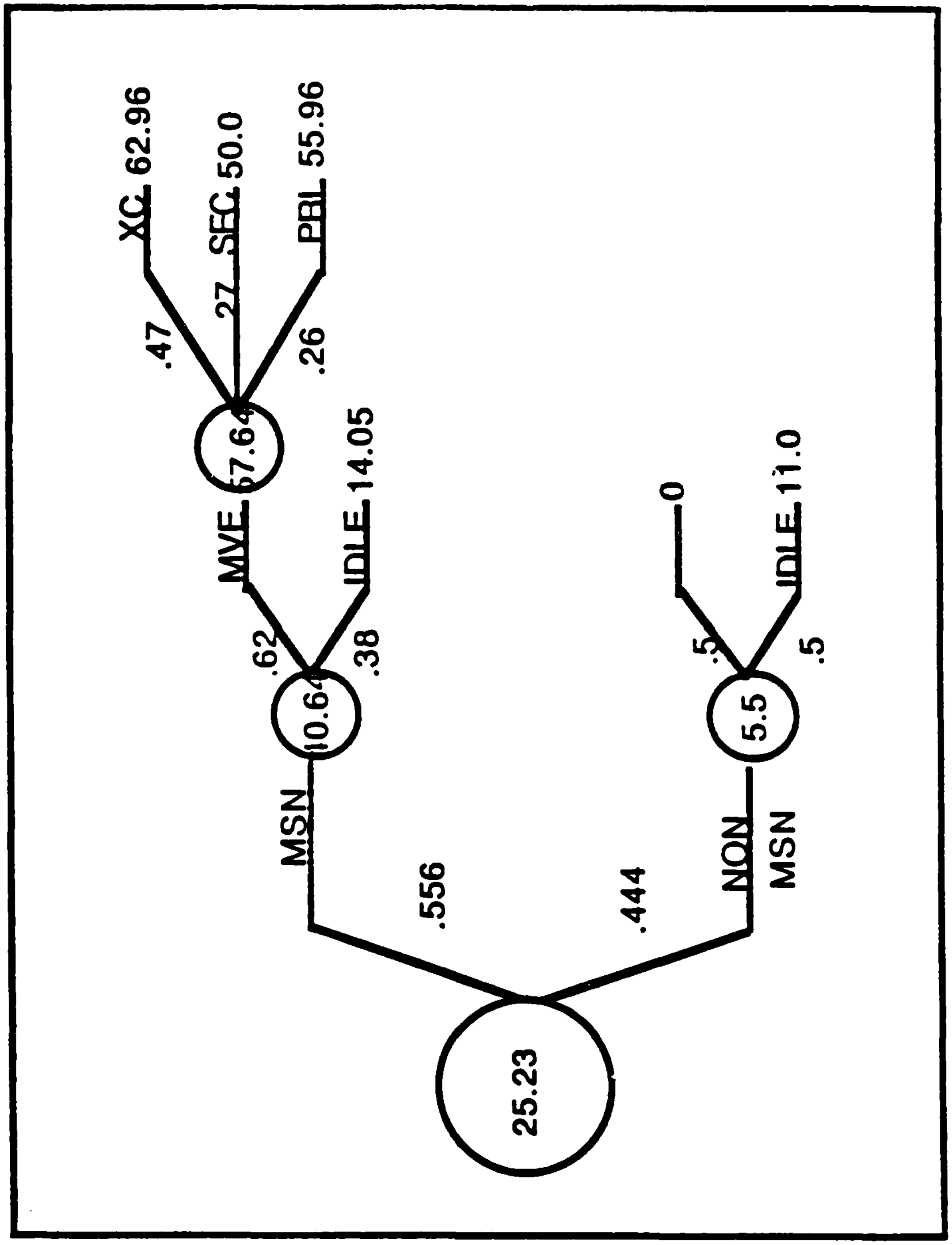

Figure 13. Fuel Consumption Coefficient Tree

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VITA

Captain John K. Langhauser was born [redacted], in [redacted]. In 1973, he graduated from [redacted] and received an appointment to the United States Military Academy at West Point. In June 1977, he was graduated with a Bachelor of Science degree and commissioned as an Armor officer. Captain Langhauser served as an executive officer and a company commander of an Infantry basic training company at Fort Knox, Kentucky, before he was assigned to the 2d Armor Cavalry Regiment in the Federal Republic of Germany. He served as a cavalry platoon leader and executive officer in the 1st Squadron prior to being assigned as the regimental maintenance officer. He then was reassigned to the 194th Armor Brigade, Fort Knox, where he served as the S-3 (air) for the 5th Battalion, 73d Armor and commanded in succession the battalion's Combat Support Company and D Company. After command, he was selected as the Aide-de-Camp to the Commanding General, US Army Armor Center and Fort Knox. Captain Langhauser's military schooling includes the Armor Officer Basic and Advanced Courses, Airborne School, and Ranger School. In June 1986, Captain Langhauser entered the Air Force Institute of Technology at Wright-Patterson AFB, Ohio.

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The tank battalion's success in combat depends, to a great extent, on the ability of the logistical system to provide adequate support. The primary objective of this research effort was to develop a methodology for use in evaluating the ability of the tank battalion to resupply itself with fuel.

The methodology includes a model that is predictive and sufficiently realistic for use as a decision support tool. It combines analytical and Monte Carlo techniques. This model is analytic in its use of classical Lanchester theory to deterministically model the attrition of tanks and resupply vehicles. Recognizing the parallels between the attrition of equipment and the consumption of fuel, Lanchester's equations, as expanded to represent combat between heterogenous forces, were also used to model fuel consumption. Stochastic techniques were incorporated in the model to represent the randomness of the combat environment. The actual number of surviving vehicles able to conduct refuel operations was determined by a draw from a binomial distribution.

The result of this effort is a robust model that the U.S. Army Armor Center can use as an analytical tool to assist in the analysis of Class III combat service support systems.